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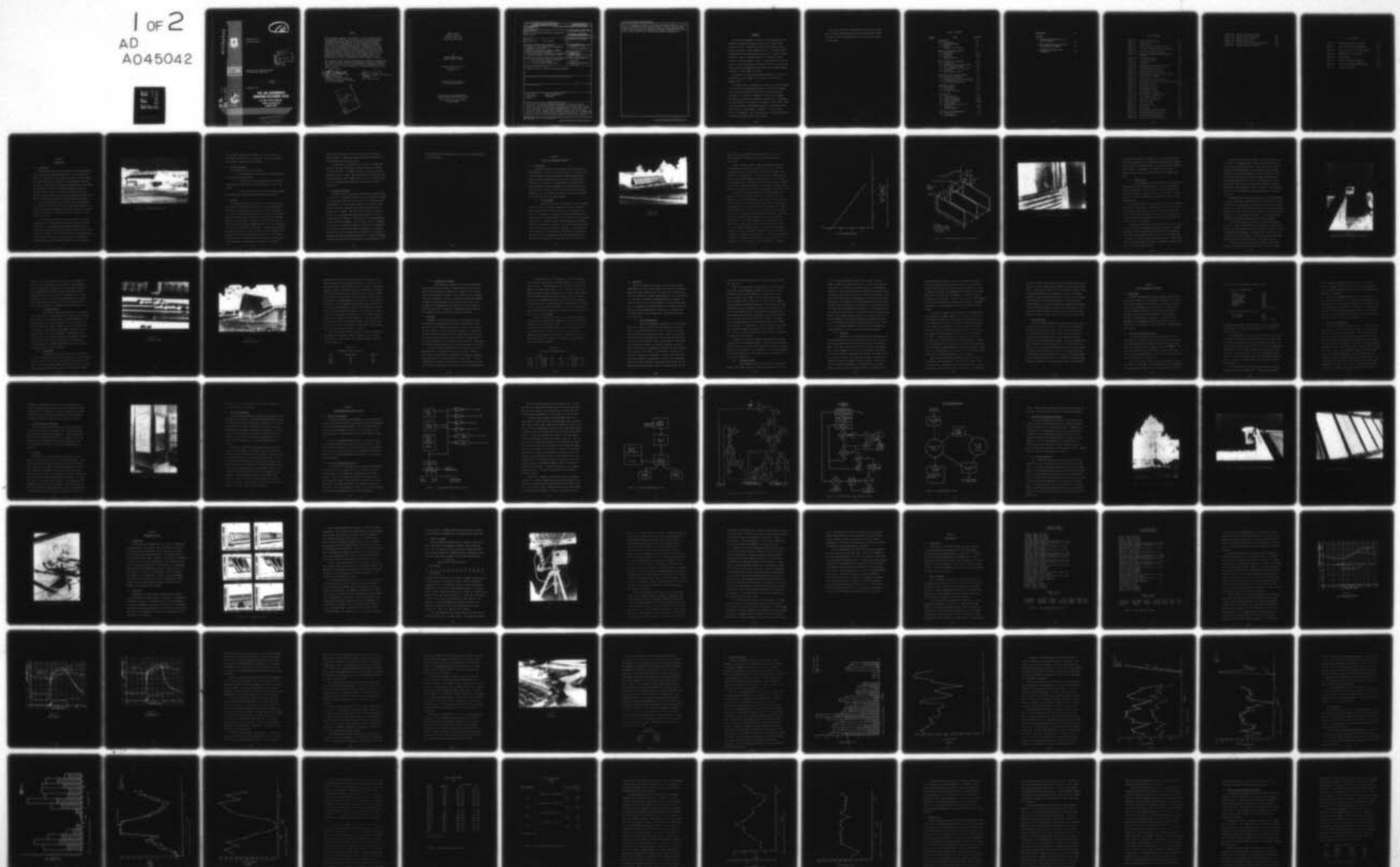

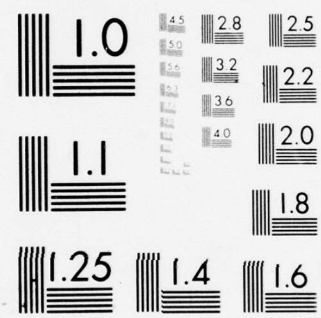

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SECOND INTERIM TECHNICAL REPORT ON USAFA SOLAR TEST HOUSE

SEPTEMBER 1977

CIVIL AND ENVIRONMENTAL
ENGINEERING DEVELOPMENT OFFICE
(AIR FORCE SYSTEMS COMMAND)
TYNDALL AIR FORCE BASE
FLORIDA 32403

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JOHN J. RUSSELL, Major, USAF
Director of Research
Department of Civil Engineering,
Engineering Mechanics & Materials
U.S. Air Force Academy

JOSEPH S. PIZZUTO, Col, USAF, BSC
Commander
Det 1 HQ ADTC (AFSC)

SECOND INTERIM
TECHNICAL REPORT ON
USAFA SOLAR TEST HOUSE

by

Captain Anthony Eden
Captain John T. Tinsley

Technical Report TR-77-34
September 1977

Department of Civil Engineering,
Engineering Mechanics and Materials
United States Air Force Academy
Colorado 80840

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This report describes the continuing performance of the first retrofit-constructed, solar-heated facility in the USAF, the Solar Test House at the USAFA. The attempts at improving the performance of the system have centered on the following: additional heat exchangers; bleed air line and valves; ground array angle changes; reduced volume of storage tank; control temperature reductions; flow rate reductions and new data gathering system. The Solar Test House was modified to conserve thermal energy by using urea foam insulation → on

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20. in the ceilings, vestibules on the doors, and linear diffusers for the duct outlets. Thermography studies have been started to explore the flow patterns through the solar arrays and correlate pictures with multiplexed sensor readings. Daily, monthly, and yearly data analysis is reported to show the effects of the various system and operational changes and the improved performance.

FOREWORD

This report was prepared by members of the Department of Civil Engineering, Engineering Mechanics and Materials (DFCEM), USAF Academy, Colorado. The work was initiated under Frank J. Seiler Research Laboratory, Project Number 2303-F1-75. The project investigators were Captain Anthony Eden, Captain John T. Tinsley, Captain William A. Tolbert, and Captain William J. McClelland. Project Director was Colonel Wallace E. Fluhr. Funding support was from the Air Force Civil Engineering Center (AFCEC) and the Civil and Environmental Engineering Development Office (CEEDO) under Program Element 64708F and Job Order Number 2054 5005.

This report covers work accomplished from May 1976 to April 1977. This manuscript was released by the authors for publication in September 1977.

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The authors are grateful to Miss Alice Amrine for her professional drafting assistance and Mrs. Penny Grayson and Mrs. Gladys DiLorenzo for their dedicated efforts in proofing and finalizing the manuscript.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This interim technical report describes the continuing performance of the Solar Test House at USAFA (Fig. 1-1) from May 1976 to April 1977. This report is the second in a series of reports aimed at evaluating the data collected by the data and control system at the house. Data analysis, evaluation of modifications made to improve the performance of the various components and the evaluation of improved overall efficiency are the main thrusts of this report. The first interim technical report, FJSRL TR 76-0008, September 1976, should be referenced for details on original system construction.

The project coordination with the Air Force Systems Command has been shifted from the Air Force Civil Engineering Center to the Civil and Environmental Engineering Development Organization (CEEDO). Support for the project continues to come from the Frank J. Seiler Research Laboratory.

This report should provide a base of information for use by engineers in the field while analyzing various designs for possible problem areas. By enumerating the difficulties observed with an operating solar energy system, by analyzing the effectiveness of the attempted corrections, and by illustrating the efficiencies possible from such systems, this report can be referenced as a measure of performance and a source of possible solutions to future problems.

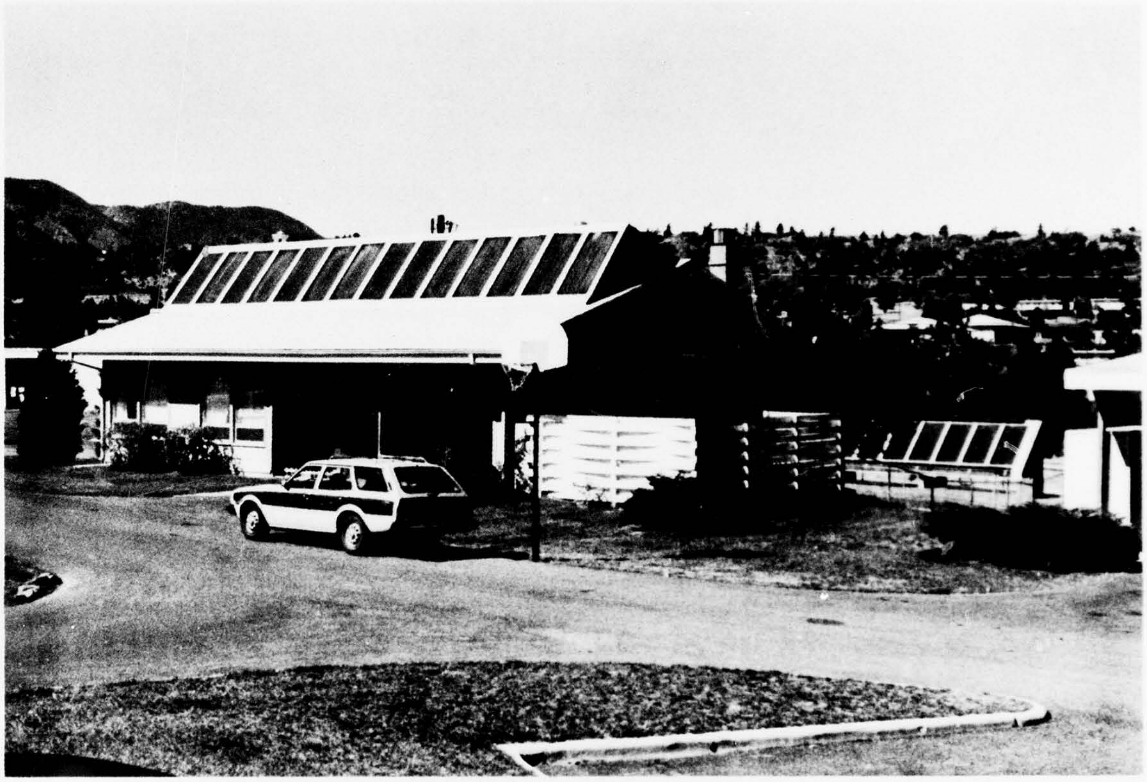


Figure 1-1. USAFA Solar Test House

In this light, emphasis will be placed on observations of the researchers in areas difficult to quantify. Data and its analysis are included to substantiate actual results.

1.2 Project Objectives

The objectives of this project remain:

a. to develop baseline design criteria to support future Air Force solar energy programs;

b. to obtain sound design, construction, and operations and maintenance experience in real property-oriented solar energy systems;

c. to obtain sound cost data on such solar energy systems upon which future economic effectiveness models may be based.

1.3 Approach

The approach taken during the first year of operation of this solar energy system was that of observing the various components in operation and the effects of the parameters on overall efficiency. The primary concern during the early stages of the project was operation and refinement of the interface of the collector, storage tank and house heating systems. The analysis of the data collected was handled through the computer programs designed to give the researchers the most vital information at first glance. Detailed analysis of the more technical areas were covered by further computer analysis or by assigning those areas to cadets as special projects. This series of priorities led to emphasis being placed on maintaining the system at top performance and addressing the problems with performance

directly as they appeared. As will be discussed in this report, various attempts at improving that performance were successful, and the data analysis will show the extent.

The units used in this report are a mixture of English and SI. The data system and daily analysis computer program used English units until May 1977. The summaries listed for monthly and yearly performance are in SI units. Where appropriate, both types of units are given; however, due to common practice in the construction industry, heat transmission and resistance coefficients are listed in English units.

1.4 Contents of the Report

This report covers the period of data collection from May 1976 to April 1977. The overall performance period is extended to include the very earliest operations to show the effects of operational and system changes. The use of energy conservation techniques is discussed to illustrate the effects on system performance when the heating load is reduced. This area could be applied to any type of structure, not just those with solar energy applications. The control system was modified to increase accuracy of measurement and to allow additional parameters to be analyzed. The use of thermography, itself a new field, is covered to show its direct application to solar energy subsystem performance determination. An extensive section of the report discusses the data obtained during operation and its daily, monthly and yearly significance. Finally, conclusions reached during this period of operation and recommendations for the

future are listed to illustrate the scope of the continuing research at this test house.

CHAPTER 2

SYSTEMS AND OPERATIONAL CHANGES

2.1 Ground Array

The ground array (Fig. 2-1) was chosen as a test bed for the modifications to be made to the collector loops. The ground array's location allowed quick and easy access for making these changes without the safety hazards and multiple trusses encountered when working on the roof array. The changes made on the ground array were the addition of a heat exchanger to the collection fluid loop, the addition of a bleed air line to the collectors, the variation of the slope of the array itself, the addition of air pressure gauges, and the insulation of the plumbing raceways.

2.1.1 Heat Exchangers

During the first year of operation of the solar energy system, there was a significant temperature difference during the heat exchange between the collection fluid and the storage tank water. The temperature of the fluid in the heat exchangers was not unexpected, as all heat exchangers have an efficiency of heat transfer less than 100%. However, the heat transfer temperature difference dictated the temperature returning to the collectors during operation and thus directly affected collector efficiency. Solar energy collector efficiency is a function of the temperature of the fluid in the collector and the temperature of the panel absorbing surface. The higher the temperature of a flat plate collector surface, the

Figure 2-1

Ground Array

larger the driving temperature difference between the collector and the ambient air, and the lower the collection efficiency (Fig. 2-2).

During the summer of 1976, another heat exchanger was added to the ground array collection fluid loop (Fig. 2-3). This heat exchanger was exactly the same type as originally installed, sheet and tube, steel construction. It was installed in parallel with the other two heat exchangers and was located within 10cm of the center of the storage tank. A dielectric union was again used in an attempt to isolate the steel heat exchanger from the copper plumbing. During this work, corrosion on the other heat exchangers was noted (Fig. 2-4).

Operation of the ground array collection loop changed with respect to that of the roof array after this modification. The temperature of the water returning to the ground array more closely approximated that of the storage tank. The difference between the temperatures into and out of the ground array remained as it should, but the temperature of the whole circuit tended to be lower than the roof array. This led to two system operational changes. First, the ground array would apparently function at a higher efficiency of collection due to the lower temperature of the collection fluid. This point was never specifically tested but placing both arrays at the same angle during the winter of 1977 will allow this determination. Secondly, the ground array tended to stop operations in the afternoon sooner than the roof array. The controlling temperature difference for collection loop operation is that between the water coming out of the array and the storage tank itself. The ground

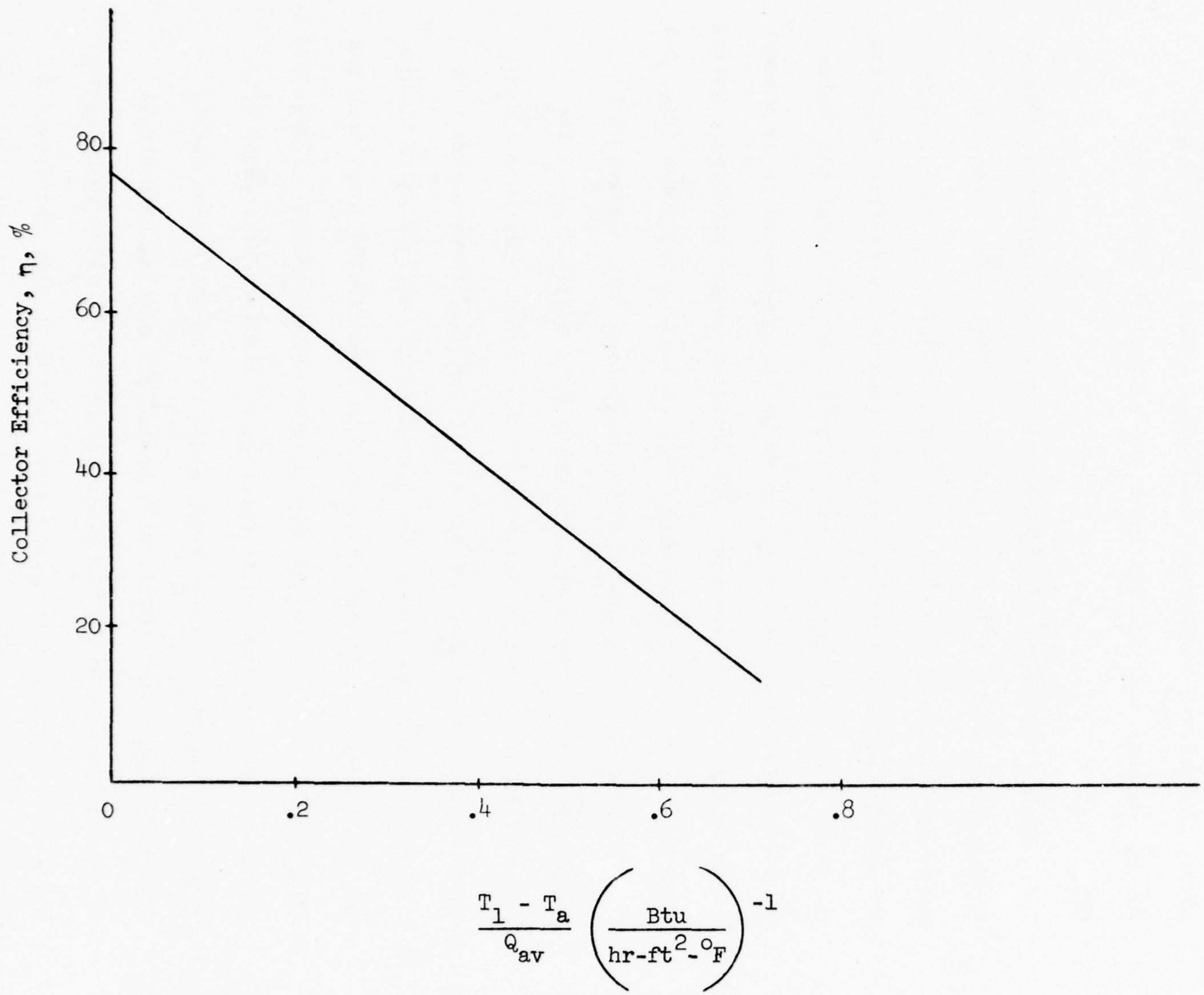


Figure 2-2. Typical Collector Efficiency Curve (Ref. 2)

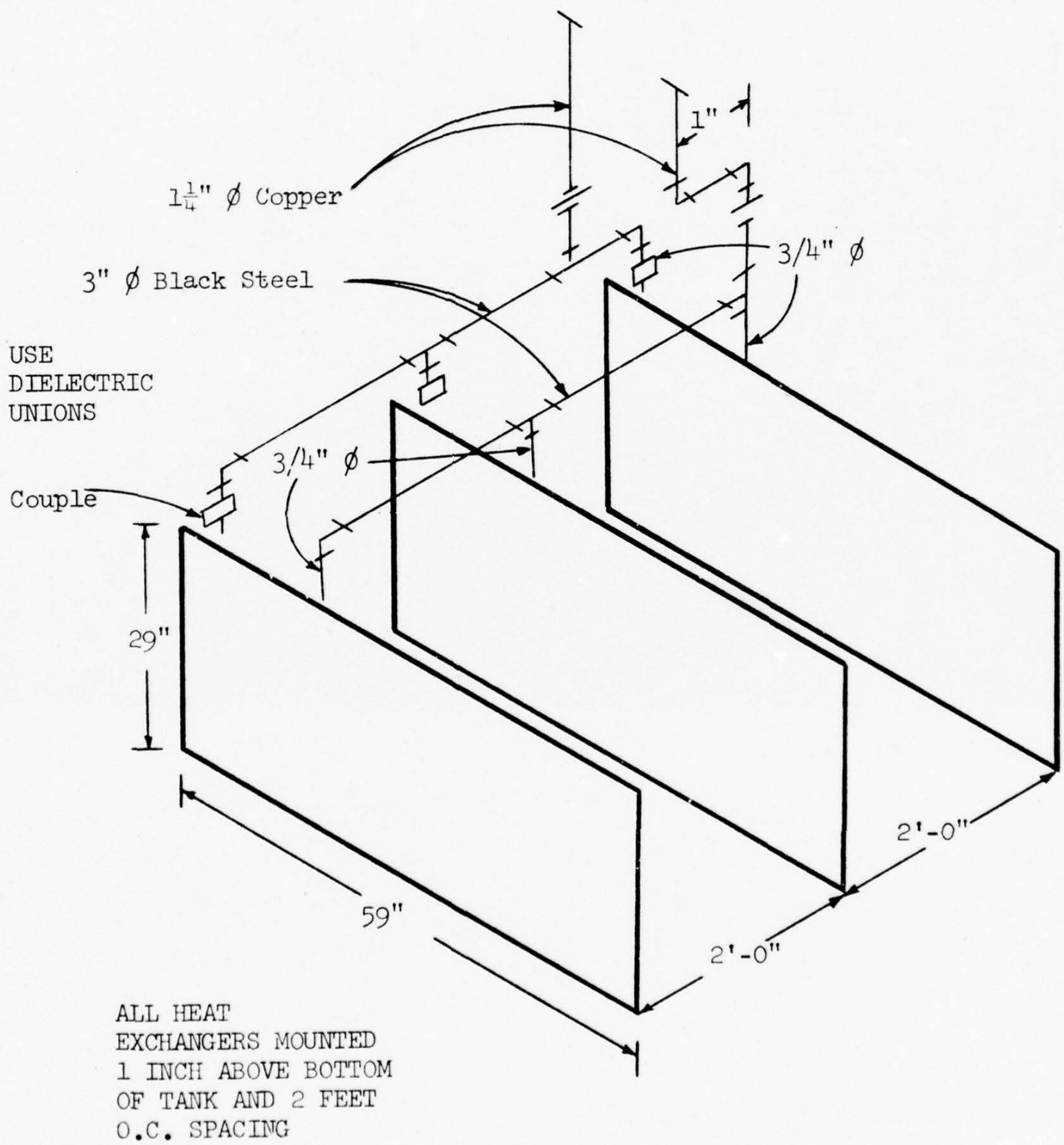


Figure 2-3. New Heat Exchanger Loop on Ground Array

Figure 2-4. Corrosion on Heat Exchangers

array would always reach the temperature of the storage tank first and would be shut down by the microprocessor approximately 15 minutes earlier than the roof array each day. Thus, the extra heat exchanger acted two ways: it allowed the operation of the collectors at a higher efficiency, and it caused the collection of energy to stop sooner.

2.1.2 Bleed Air Line

Air entrapment in the solar collectors has plagued this system since it first started operation. In the parallel-series plumbing arrangement it was easy for air to become trapped at the top of the collectors. This was because of two problems: no route for the air out of the system and the balancing of a direct return plumbing system.

The original design of the collector loops included an expansion tank and an air vent valve. On the ground array, the air vent valve occasionally did entrap some air but it did not on the roof array system. The tendency for the air to rise to the high point of any system forced the air to the top of the roof array and usually into the third cluster of collectors.

The direct return method used in plumbing the clusters of collectors in parallel was inherently difficult to balance. Although balancing cocks were installed, and eventually pressure gauges as well, until the multiplexer discussed in Section 4 was operational, no reading of the actual flow pattern was possible. A reverse return system would have allowed the system to automatically balance at the added cost of extra copper piping.

Thus, once air got into the system, it was not removed by the air vent nor the plumbing design. The air would gather at the top of a collector and block the flow of fluid up one of the parallel tubes on the absorbing surface. This blockage would stop energy collection in that area and elevate the surface temperature. This would further aggravate the problem by flashing the nearby water and ethylene-glycol mixture to steam. The pressure in the total system would raise and the "hot spot" would promulgate across the panel until complete blockage occurred. Eventually, whole clusters would stop collecting energy, thus reducing the effective area for collection.

The ground array was modified to attempt to solve this problem. A 0.635cm (1/4") copper tube was attached to the petcock on the upper left-hand side of each panel. The tube was then connected to another 0.635cm (1/4") copper tube running the length of the array and sloping upward to the right. At the end of the tube was located an expansion tank (Fig. 2-5) and another air vent valve. All the petcocks were opened and the collection system allowed to operate normally.

The bleed air line was also used for the initial charging of the array. A small submersible pump was attached to the end of the return water line and turned on while in a bucket containing a mixture of water and ethylene-glycol. The petcocks were opened one by one until all the air was forced out. However, minute leaks were always present and the air would eventually get back into the system.

The bleed air line did not appear to have any effect during operation of the collector loops at full flow. Air still became

Figure 2-5

Ground Array Expansion Tank/Bleed Air System

entrapped in the ground array almost as fast as the entrapment in the roof array. Approximately once per month, a normal recharge had to be accomplished. However, after the multiplexer (Section 4) and the thermography (Section 5) results were studied, and half speed flow was chosen, the bleed air line appeared to be effective. The ground array did not show the high temperatures that accompany an air blockage while the roof array still was blocked as usual. The flow rate change is more thoroughly discussed in Section 2.3.3.

2.1.3 Air Pressure Gauges

In an attempt to gain information on the flow patterns in the ground array, air pressure gauges were added to the collection loop (Fig. 2-6). These gauges would allow direct observation of the actual pressure at the strategic points of flow such as into and out of the clusters of panels. However, the actual differences in flow pressure at these points were so small, the accuracy of the gauges would not allow its determination. The pressures during operation of the loops, when the gauges at the pump would indicate 83 KPa (12 psi), were usually 55 KPa (8 psi) into a cluster and 28 KPa (4 psi) out. As evidence later would show, this was not an accurate indication of the flow pattern.

2.1.4 Angle Change

The ground array was constructed to allow changes to be made in the angle with respect to the horizontal to three settings: 45^{o}, 52^{o} and 60^{o}. On 1 Oct 76, the ground array was jacked up by a crew of five men and the 60^{o} saddles were installed (Fig. 2-7). This change allowed the ground array panels to be more closely aligned

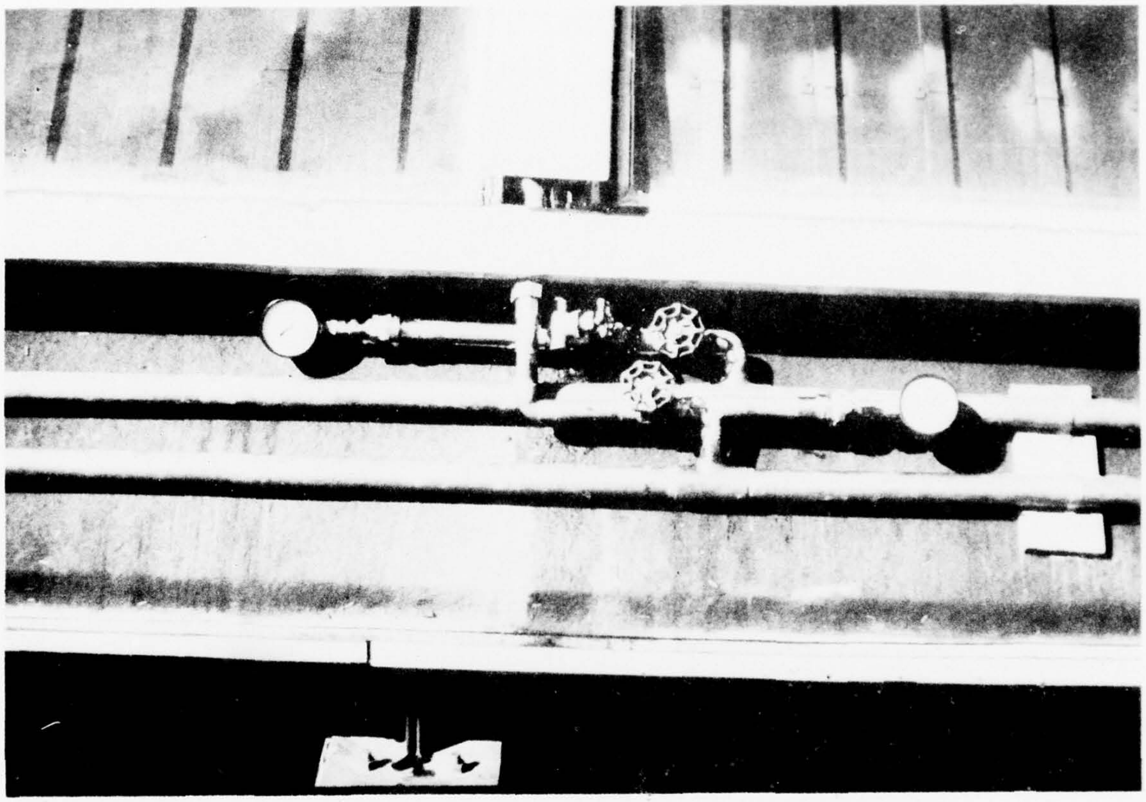


Figure 2-6

Air Pressure Gauges

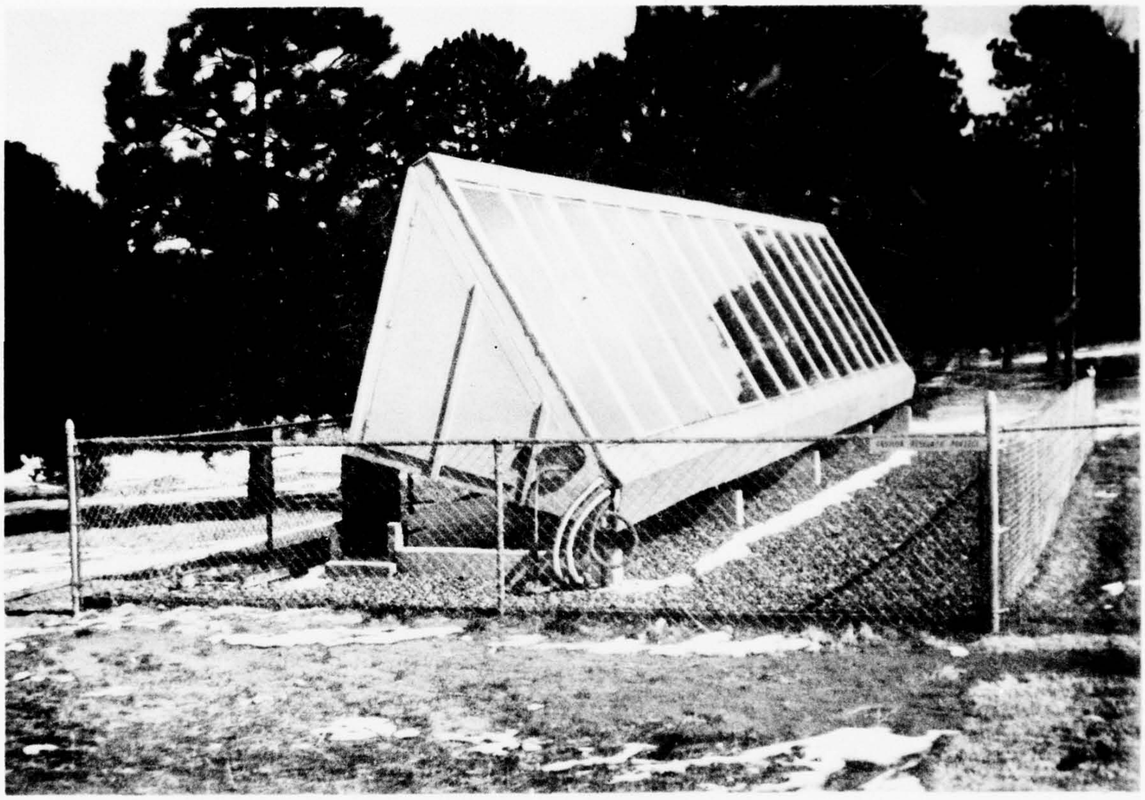


Figure 2-7

Ground Array at 60^{o}

perpendicular to the sun's rays during the winter months. As is shown in Appendix B, the available insolation to a collector at 60° was greater than at 52° from approximately 3 November to 20 February. During this period the ground array did function most of the time at a better collection efficiency than that of the roof array. However, exact figures on how much better were difficult to calculate due to continuing air blockage problems and the presence of the third heat exchanger. The direct evidence was the higher temperature difference that occurred between the fluid into the ground array and then back to the storage tank when compared to the roof array. Caution was used in determining efficiencies due to air blockage problems on the roof also elevating the water temperature. Since flow rate was based on valve position, the analysis program could erroneously calculate a high level of efficiency with high temperatures at reduced flow. This is discussed in detail in Section 6.5.

On the other side of winter solstice the ground array angle of 60° becomes less efficient at about 20 February and it should be lowered back to 45° by 3 March. The recommended angle changes are listed in Table 2-1.

Table 2-1

Recommended Ground Array Angle

Date	Present Angle	Change To
3 Oct	45°	52°
3 Nov	52°	60°
20 Feb	60°	52°
3 Mar	52°	45°

2.1.5 Insulation of Raceways

Both arrays are constructed with steel flashing covering the space between the panels. This flashing protects the copper piping that runs between the panels and the supply and return lines that are located below the panels. These raceways were not insulated when first constructed. This lack of insulation allowed great amounts of energy to escape the piping as it returned the hot water to the storage tank. Fiberglass batts were installed in these raceways to cut this loss as much as practical. Thermography studies before and after showed that this insulation was extremely effective.

2.2 Tank Mass

Throughout the first heating season, the storage tank volume was maintained at approximately 9464 liters (2500 gallons) of water. This mass of water allowed the storage tank to store the solar energy for use overnight to satisfy the house heating load. As mentioned in the first interim technical report, this volume of water was too large for this particular application, being outside of the usual range of 60 to 100 liters/sm (1.5 to 2.5 gal/sf) of collector area. This problem was somewhat solved by decreasing the storage tank volume in July 1976.

In order to lower the water level in the storage tank, the heat exchangers had to be lowered to the bottom of the tank. This was done in order to allow the heat exchangers to be completely submersed in the water when the tank was filled to its final level. The heat exchangers were dropped to within 2.5cm (1") of the bottom of the tank and the water was refilled to a new level of 6814 liters (1800 gallons).

The immediate effect of this change was the predicted faster reaction of the storage tank to the high temperature water from the collector loops. The tank temperature now could raise quickly to a higher, more usable range. This in itself allowed more use of the energy collected for house and domestic water heating. When combined with the control temperature changes discussed in the next section, this led to a tremendous increase in the overall solar contribution to the house loads. A further reduction to 4921 liters (1300 gallons), a ratio of 90.41 liters/sm (2.26 gallons/sf), will be accomplished when the foot valves are lowered in the storage tank to be level with the top of the heat exchangers.

Table 2-2 illustrates the effects of the lowered tank volume on the rise of the storage tank temperature (ΔT). The dates chosen were before and after the volume change. Less energy was required to obtain the same temperature rises after the volume reduction. This was significant in that it took into account the ambient temperatures that existed by the comparable degree days (DD). The temperature rises were, therefore, the result of less water mass and not less severe conditions.

Table 2-2

Effects of Tank Volume Reduction

Before				After			
Date	ΔT	Btu Coll.	DD	Date	ΔT	Btu Coll.	DD
29 Jan	4	327,388	25	1 Oct	4	225,592	23
11 Feb	7	417,069	28	16 Oct	9	392,743	28
13 Feb	13	630,018	22	22 Oct	12	409,333	23

2.3 Operations

After the operation of the solar energy collection system progressed for one year, the efficiency of the use of the collected energy was noted as being too low. The first year's operation saw the solar contribution to house heating demand to be 42% (see Section 6 for details). This level of performance had to be improved to illustrate the effect of various parameters on overall system operation. As discussed in the previous section, the volume of water in the storage tank was decreased as a first step. The other areas of changes were the control temperatures, the shutdown procedure and the flow rate.

2.3.1 Control Temperatures

The control temperature originally used for the selection of the storage tank water for house heating was set at 40°C (104°F). This definitely allowed hot air to be used in the solar house through the existing ducting system. However, as previously discussed, this also precluded use of the storage tank water until that temperature was reached. Many days were spent at 39°C (103°F) and no energy was supplied to the house for heating. The first attempt at lowering this temperature occurred in December 1976 when it was lowered to 34°C (94°F). The occupants were advised to be conscious of any drafts or discomfort. The use of the lower tank temperature immediately allowed greater usage of solar energy and improved collection efficiency of the panels by decreasing the fluid temperature returning to them. Overall, dramatic changes occurred

in the efficiency of the solar system to supply energy to the house (see Section 6).

After the initial success of this change, a further reduction of the tank control temperature followed. On 9 March 1977, the temperature was set at 32°C (90°F) and on 5 April 1977, it was further lowered to 30°C (86°F). The use of this water reduced the air temperature in the plenum to 27°C (80°F). These changes were made without informing the occupants. The balance of the solar house distribution system became a problem at this point due to the sensor for thermostatic control being located in the living room. The southwest bedroom began to be reported at 14°C (58°F) when the rest of the house was at 18° to 19°C (65° to 67°F). On 18 March, the desired temperature was raised from 19°C (67°F) to 20°C (68°F) by the occupants. No discomfort was reported throughout this period even though the occupants were advised of the changes at a later date. The use of linear diffusers discussed in Section 2.4 may have contributed to this situation.

In March the lowered tank control temperature and the reduced volume began to allow storage overnight. During April, this storage began to increase to over one day's cloudy period. These both directly illustrate the increased use of solar energy in the house for heating and the continued ability of the storage tank to cover periods of no solar energy collection.

2.3.2 Shutdown Procedure

During operations of the solar system in the months of November and December 1976, the control of the shutdown at the end

of the collection day began to show a lack of speed. The valve opening sequence was to move in one step to half open and then use 95 small steps to full open if the solar energy was of a high enough intensity to raise the collector water temperature at least $6^{o}C$ ($10^{o}F$). For shutdown, small steps were used all the way from full open to full closed (255 steps total). During periods of low insolation, and cold temperatures, the shutdown at one step per eight seconds was too slow. Collector fluid would continue to flow through the panels for up to one half hour after the beginning of the shutdown. The shutdown procedure was changed to three steps at a time during closing and one step during opening. This allowed quicker reaction by the variable valve to the closing commands but still would allow gradual opening during start up, or the passage of individual clouds across the area. The situation of fluid flowing through the storage tank heat exchangers and taking energy out to the collectors was completely eliminated.

2.3.3 Flow Rate

Perhaps one of the most significant changes made to the system during this last year of operation was that of the flow rate. The previous operation of the system called for 60.6 liters/min (16 gpm) at full open. This flow rate into the parallel-series combination of panel plumbing led to a ratio of 2.634 lpm/sm (.065 gpm/sf) in the three collector clusters and 1.975 lpm/sm (.049 gmp/sf) in the four collector clusters. This flow rate was higher than the recommended 0.81 lpm/sm (0.02 gpm/sf) for water systems. This high flow rate also promoted the formation of air bubbles in the system by slight cavitation at the centrifugal pump and the breaking up of the

small bubbles near the valve. Once the air formed, or leaked into the system at night, the high flow rate forced it to the top of a collector cluster, and the air blockage problem occurred. As will be discussed in Section 5 on thermography and Section 4 on the multiplexer, the flow pattern at full open was not constant and equal throughout the total system. The high level of friction that resulted from this flow contributed to the unusual flow patterns. All these indications led to the decision to slow the flow to half open as a maximum.

The flow rate change was made through the microprocessor which was programmed to no longer command 255 as full open, but use 160. This command corresponded to 30.3 lpm (8 gpm) during the original flow calibration at the start of the project. The immediate effect of this change was the doubling of the temperature rise from the collectors. When a typical day previously had a $6^{O}C$ ($10^{O}F$) rise in the temperature of water going to the arrays, the rise now became $12^{O}C$ ($20^{O}F$). At times during the first month of this half flow operation (April 1977) the temperature rise exceeded $12^{O}C$. This led to an investigation of the actual flow rate in the present system by using the annubars already installed and a diaphragm, dynamic pressure meter. This investigation is still ongoing, with initial indications of less than 30.3 lpm being obtained at the 160 command.

Other effects of the flow rate change included the reduction of air blockage in the ground array. The ground array showed a more normal temperature distribution across the clusters with no apparent air blockage. More details on this are included in the thermography

section. The roof array still had the same indications of air blockage, with the third cluster being extremely hot when compared to the others. The half flow position of the valve caused a larger pressure drop across the valve of up to 10,000 Pa (15 psi). And finally, sending the higher temperature water back to the collector decreased the efficiency of the collectors themselves. This sacrifice was well worthwhile, as a higher temperature was obtained in the storage tank and longer utilization was possible for house heating. Consequently, the panel collector's efficiency was sacrificed for house heating efficiency, the main application of the solar energy system.

2.4 *Linear Diffusers*

As the tank control temperature was lowered the comfort of the occupants became a primary concern. The air that was eventually to blow on them was about 27°C (80°F). This air when circulated at 0.71 cms (1500 cfm) would definitely feel cool when coming out of a typical base housing floor grill. This problem was solved by installing linear diffusers with a damper. The linear diffuser mixes the air coming out of the duct with the room air and diffuses the stream so that it does not blow at high velocity for a great distance. The dampers allow the system as a whole to be balanced, with some rooms receiving full air flow and others less. The reported comfort of the occupants with air as low as 27°C (80°F) being used for house heating was evidence of the effectiveness of these linear diffusers.

CHAPTER 3

ENERGY CONSERVATION TECHNIQUES

3.1 Introduction

The USAFA Solar Test House project involved the adaptation of solar energy systems to a typical domestic dwelling. At first this retrofit application did not concern the house itself with respect to the energy consumption of this type quarters. However, during the second summer of operation, the structure's heat load was examined for possible retrofit improvements. These included increasing the insulation in the walls, ceiling and floor; the improvement of the insulation on the window panels; the use of vestibules for the two doors; and the installation of triple glazing on the windows.

3.2 Urea Foam and Ceiling Insulation

Urea foam was used as an insulation material in the walls. This material was injected into the cavities that exist in standard wood frame construction to increase the thermal resistance of the walls. The high R value of urea foam, which is $4.2 \frac{ft^2\text{-}hr\text{-}^oF}{Btu}$ per inch, make this material very applicable to energy conservation. It does not settle when installed, it is not affected by moisture, and its R value exceeds that of looser fill.

Table 3-1 shows the R values of the wall construction before and after use of urea foam. The resultant reduction of transmission of heat through the walls due to its use was anticipated at 47% or

Table 3-1. Urea Foam Effects on R Value of Wall

R value from original wall:

Surface	0.68
1/2" gyp board	0.45
1 1/2" insulation	5.00
2" air space	0.95
3/8" plywood	0.47
Waterproof paper	0.06
3/16" T.H.B.	0.45
Surface	0.17
	8.23 (U = 0.122)

R value with addition of urea foam:

2" air space	-0.95
2" urea foam	+8.40
	15.84 (U = 0.064)

1.45 MJ/hr (1378 Btu/hr). The actual effect of this modification, together with all the others to be covered in this section are listed in Appendix A.

The installation of the urea foam was accomplished very easily. The contractor drilled holes into the exterior of the wooden walls of the house and inserted the foam with water under pressure. The brick veneer walls were filled from above the walls by gaining access through the roof truss. Again, water was used to inject the foam. The entire operation was quality checked by thermographic studies and only one small area under a window had to be redone due to poor fill. The plugs that had been drilled out were replaced, sanded and repainted.

The urea foam did not have any noticeable effect on the wall integrity or paint after installation. There were no noticeable

spots of peeling or buckling either on the exterior or interior surfaces. Original concern as to the effect of the great amount of water necessary for insertion and its action on the wall material appeared to be unfounded.

Urea foam was considered for use in the roof structure as well. However, the high cost of the foam and its weight when used horizontally led to the selection of loose fill for this area. Loose fill was blown into the roof joists to a depth of 15.24 cm (6") with a U value of 0.29 and with anticipated savings of 3.0 MJ/hr (2840 Btu/hr). The total cost of the insertion of the urea foam and the adding of loose fill to the roof was $1125.00.

3.3 Other Insulation Changes

The first thermography studies performed on the USAFA housing showed that the two moveable panels under some of the windows were extremely inefficient at slowing losses. These panels consisted of one sheet of 0.635 cm (1/4") plywood with a resulting U value of 0.86. These panels were replaced on all houses on base with modular sandwich panels made of one sheet of 0.953 cm (3/8") styrene placed between two 0.635 cm (1/4") plywood panels. This construction lowered the U value to 0.30. This modification would result in an energy saving of 2.0 MJ/hr (1935 Btu/hr). The most neglected area for insulation in typical domestic dwellings is usually the floor. The crawl space beneath the houses at the USAFA was not insulated when originally constructed. To cut down on the energy losses through the floors all the houses were retrofitted with 7.62 cm (3") of

fiberglass batts between the floor joists. These batts with an R value of 11 decreased the U value of the floor from 0.310 to 0.0704. This reduction in U value would be applied throughout the structure in the rooms over the crawl space resulting in a new heat loss of 1.4 MJ/hr (1284 Btu/hr) through the 44.6 sm (480 sf) of floors.

3.4 Overall Reduction of Heat Load

The overall reduction of heat load in the house due to the use of the urea foam, roof insulation, crawl space insulation and sandwich panels is calculated in Appendix A. The new calculated heat load was 38.4 MJ/hr (36,378 Btu/hr), a reduction of 28%. The actual heat load reduction in the structure is discussed in the yearly data analysis (Section 6.3) and was approximately 27% in March 1977.

3.5 Vestibules

Vestibules are air lock-type structures that can be built around a door to decrease the air flow through it during use. These small chambers allow entrance to the structure while not allowing direct exposure of the inside to the outside ambient air. The use of vestibules was considered on the Solar Test House to decrease the air infiltration load. This was especially important considering the many tours and visitors that frequent the structure. Two vestibules (Fig. 3-1) were built over the doors. The vestibule door was designed to swing out so that it was very difficult to have both it and the main house door open simultaneously. This construction was accomplished during March 1977 and its exact effect has yet to be

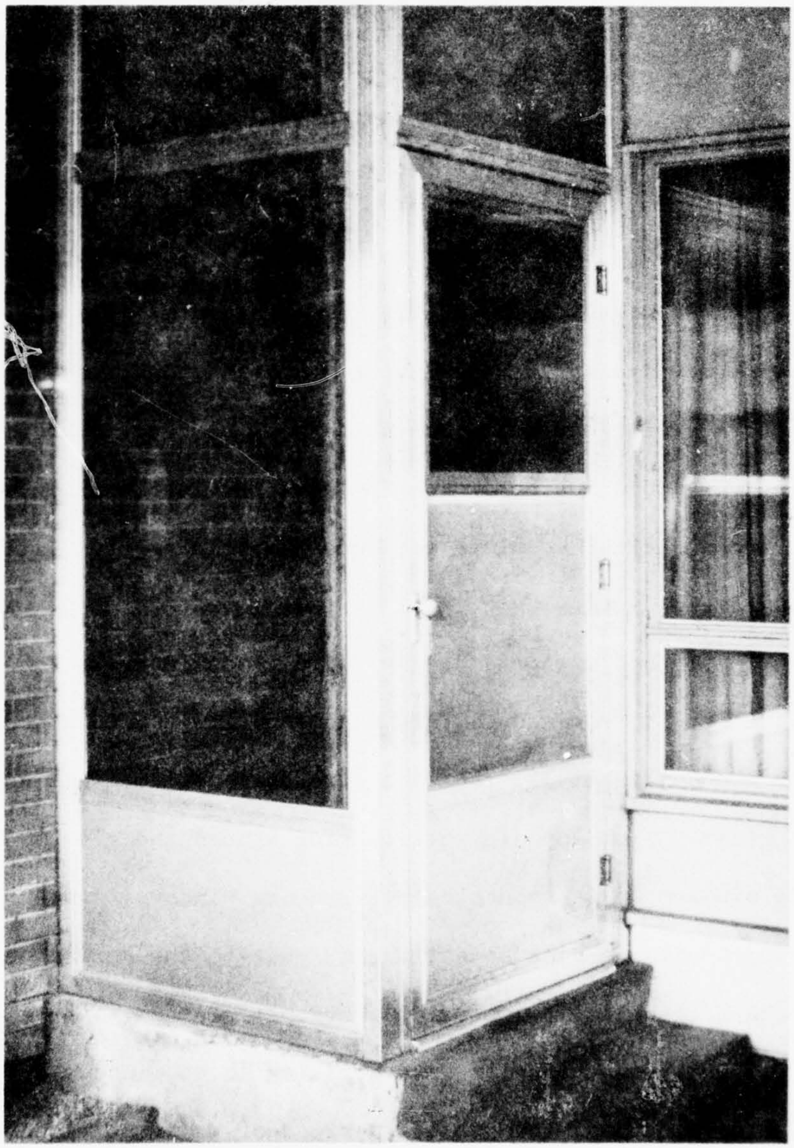


Figure 3-1. Vestibule

determined. The use of the eastern vestibule as a greenhouse has been considered by the occupants.

3.6 Triple Glazing Windows

The final energy conservation technique considered was that of triple glazing the windows. The windows presently installed consist of one pane of glass and a storm window. This system is typical for the Colorado area. However, the infiltration of cold air through these windows is noticeable during high wind conditions. The interior surface of the windows was also known to have ice form on it during very cold weather. To slow down the infiltration of cold air, and to better insulate the house, triple glazing will be employed.

The method of applying the third glass layer will be that of an interior storm window. This window will fit into the existing frame and be tightly fitted with a rubber gasket. This construction will greatly slow any air infiltrating around the glass. In using these windows on the southern two bedroom windows, another energy gaining technique will be activated. Due to the "greenhouse effect" and the better insulating value of triple glazing, a heat gain will be realized from the solar rays striking those windows during the winter days. Thus, the passive aspects of solar energy can be utilized to decrease the heat load during the days when that load tends to be a maximum. These windows will be installed during the summer of 1977 and the effect observed thereafter.

CHAPTER 4

INSTRUMENTATION AND CONTROL SYSTEM

4.1 Background Information

The design, installation and debugging of the instrumentation and control system for the USAF Academy Solar Test House is described in the first interim technical report. This section of the report will describe the changes to this system. A block diagram of the instrumentation as of the publishing of this report appears in Fig. 4-1.

As with any continuing research project, problem areas arise and unforeseen changes occur during the course of the work. Three major additions were made to the instrumentation and control system since the writing of the last report: (1) Burroughs 6700 computer conversion, (2) meteorological monitoring equipment, and (3) ground array multiplexer.

4.2 Burroughs 6700 Computer Conversion

As reported in the first report, data was gathered and punched on a paper tape at the solar house for later analysis on a Xerox Sigma-V computer in the electrical engineering lab at the USAF Academy. In the fall of 1976, this computer was declared surplus and subsequently removed. Since this was the only source of a high speed paper tape reader and the only other computer available for data analysis was the Burroughs 6700 computer, an entirely new scheme was conceived and developed for data storage and analysis.

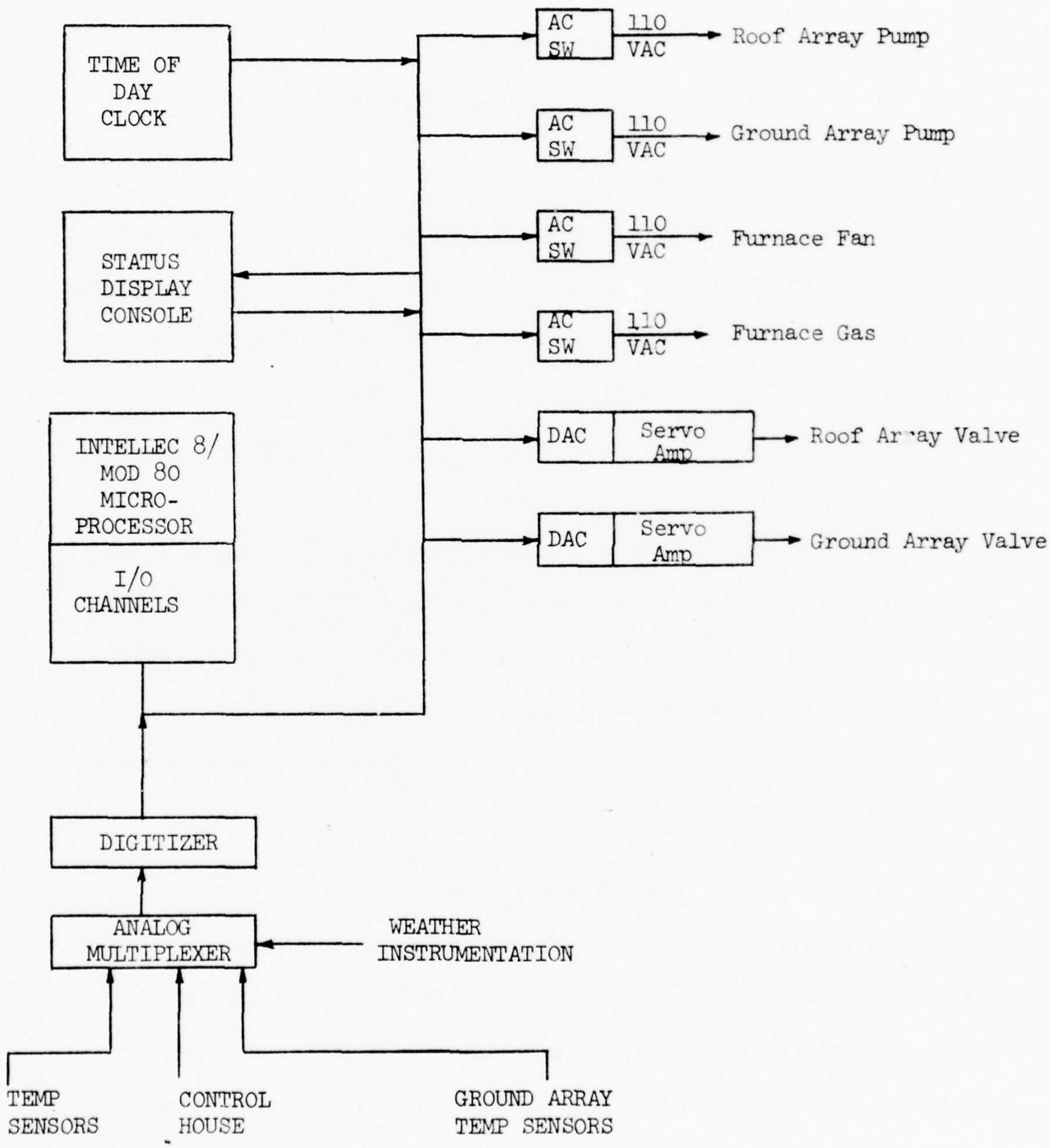


Figure 4-1. Instrumentation and Control System

The first task associated with this conversion was to design and build the temporary data storage system at the Solar Test House which would be compatible with entering data to the Burroughs 6700 computer located approximately 2.5 miles from the solar test site.

The system chosen replaced the punched paper tape with an audio cassette recorder whereby the data was stored using a frequency shift keying (FSK) scheme. This data is transferred to tape once an hour until full, approximately three days, then transmitted through a modem via commercial telephone lines to the Burroughs 6700 computer where it is temporarily stored in disk memory. The block diagram for this system showing the data flow appears in Fig. 4-2. Fig. 4-3 is a circuit diagram of the interface circuitry between the cassette recorder and the Intellec/8 microprocessor at the Solar Test House. Since the two computers have to talk on a real time basis and maintain control of the house simultaneously, a major revision to the control program was required. Fig. 4-4 shows a flow chart of this program change. Since there are at least 37,500 bytes of data on a three-day cassette, a minimum transmission time of 21 minutes is required at 300 bits/sec. As shown in the flow chart, the program maintains control of all house functions while conversing with the B6700 computer.

In addition to changes at the Solar Test House, the analysis programs were completely rewritten for use on the Burroughs system. This set of programs and their interrelationships are shown in Fig. 4-5. Since these are special purpose programs, written specifically for the Burroughs 6700 system, a listing is not provided in this

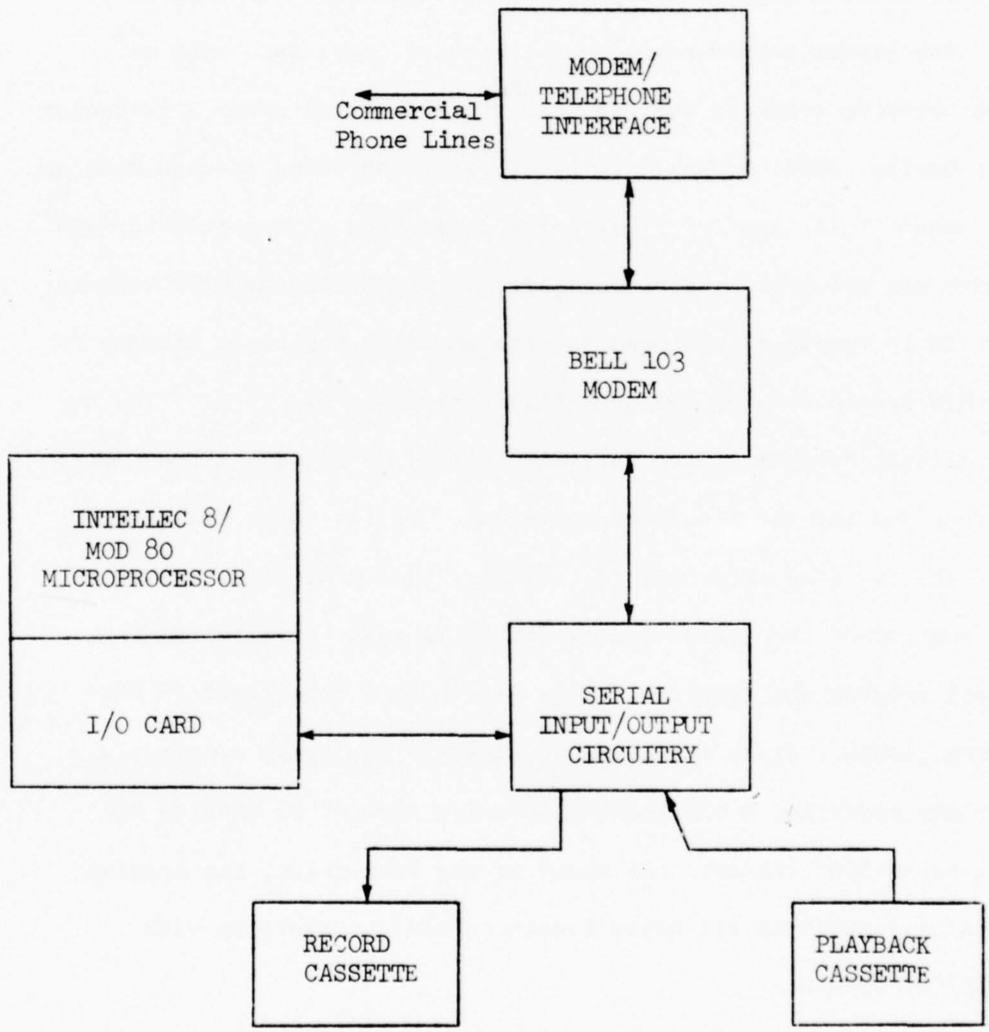


Figure 4-2. B6700 Data Recording System

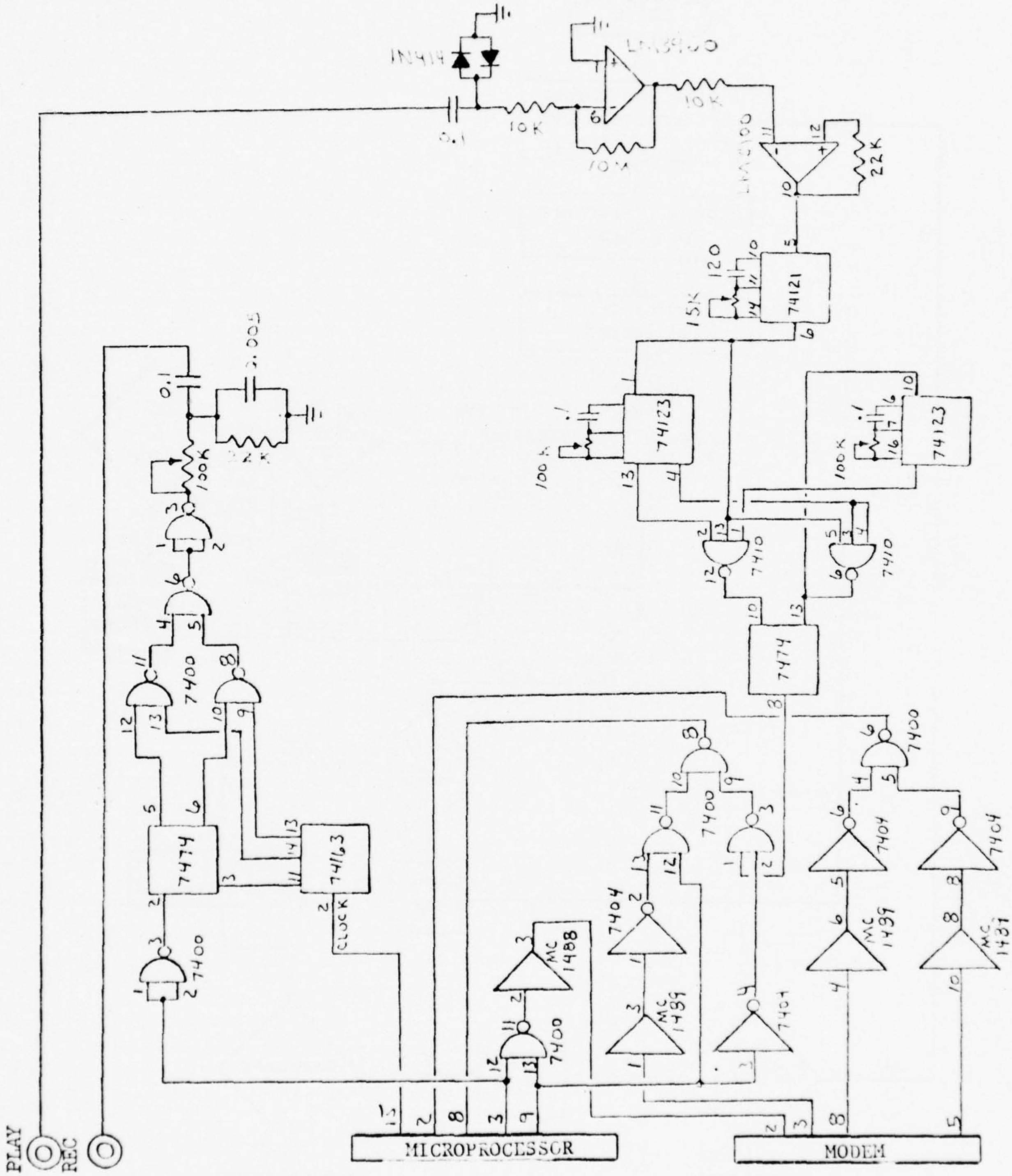


Figure 4-3. Serial Input/Output Circuitry

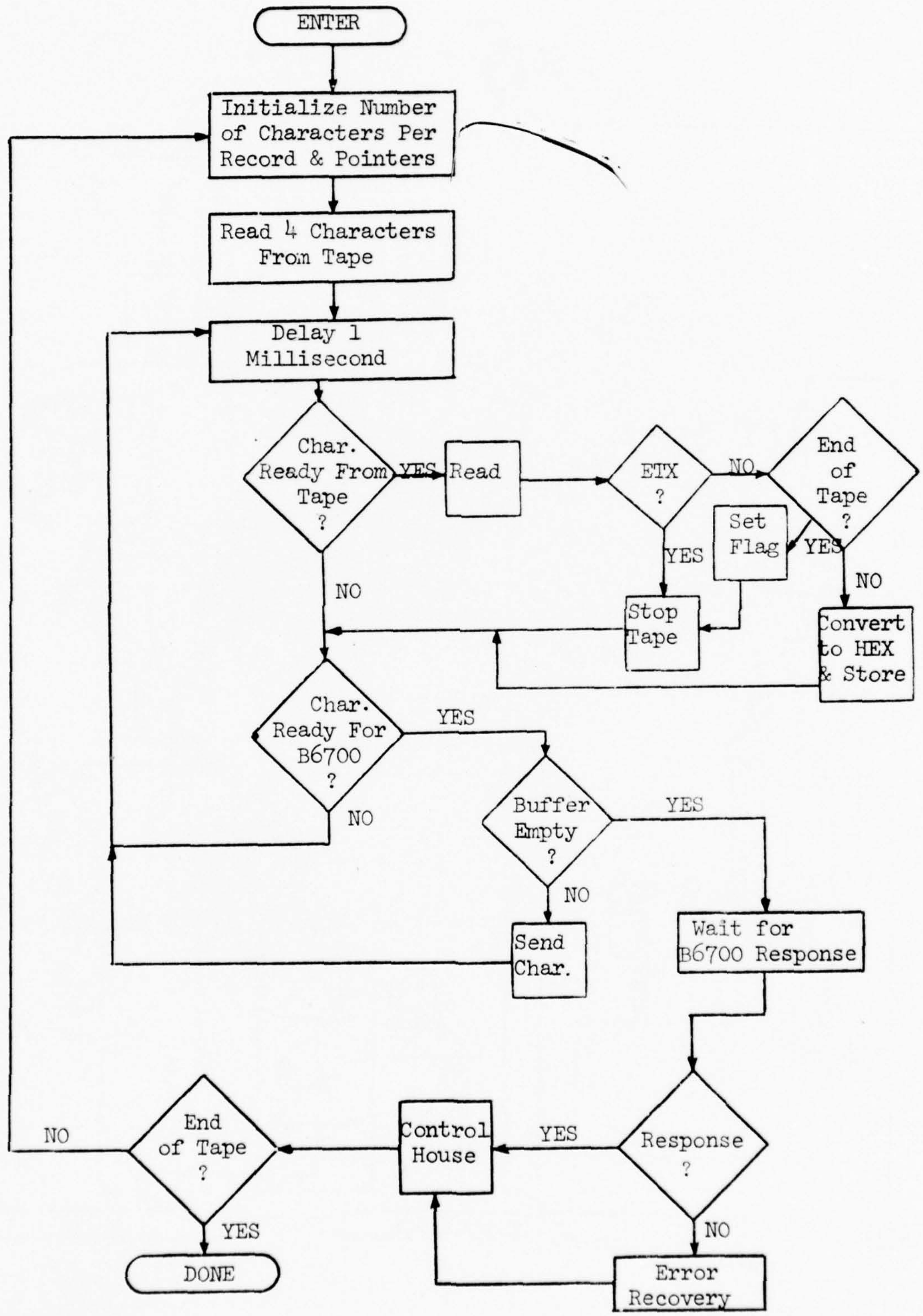


Figure 4-4. B6700/Intellec 8 Data Transfer Program

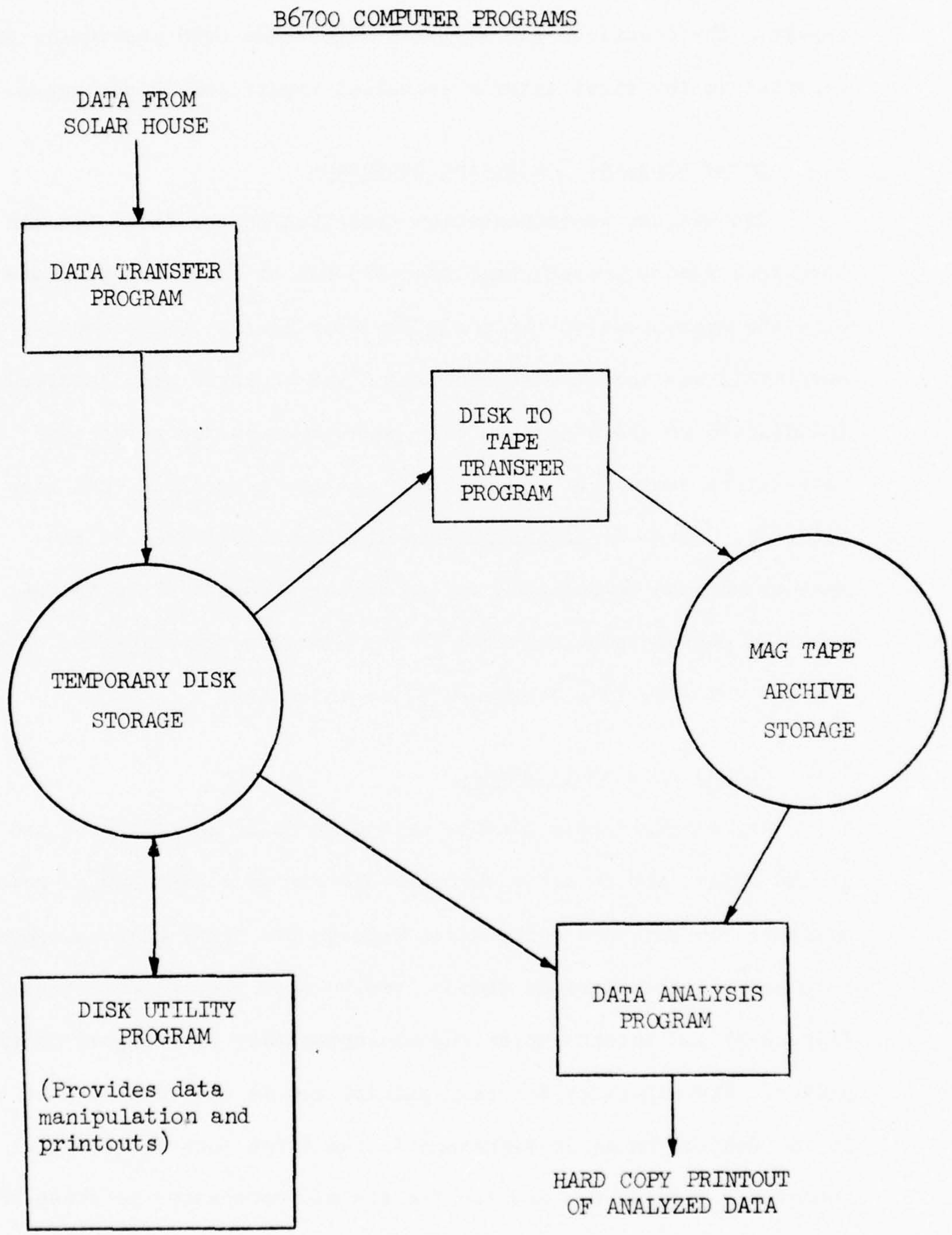


Figure 4-5. B6700 Computer Programs

report. The equations and analysis algorithms used previously and reported in the first interim technical report remain unchanged.

4.3 Meteorological Monitoring Equipment

The weather instrumentation described in the first interim technical report proved unsatisfactory due to interface problems with the microprocessor at the Solar Test House. Consequently, a completely new set of instrumentation was procured and installed. In addition to the wind direction and velocity, dew point and temperature sensors of the previous system, a barometer was also obtained. This set of instrumentation is manufactured by the Weather-Measure Corporation and is directly compatible with the 0-10V DC analog input required of the microprocessor system. Figures 4-6 and 4-7 show this instrumentation installed.

4.4 Ground Array Multiplexer

Three temperature sensors were originally installed on the ground array, two on array surfaces and one on a glass outer-panel surface. To obtain a correlation between the array surface temperature and the thermography photos, twelve more sensors were installed (Fig. 4-8) and interfaced to the microprocessor by a signal multiplexer. The circuitry for this multiplexer is the same as that used in the Control House as described in the first interim technical report. A program was written for the microprocessor to sense the fourteen temperature sensors and give a printout of their values on command. Fig. 4-9 shows the multiplexer circuitry installed in the ground array.

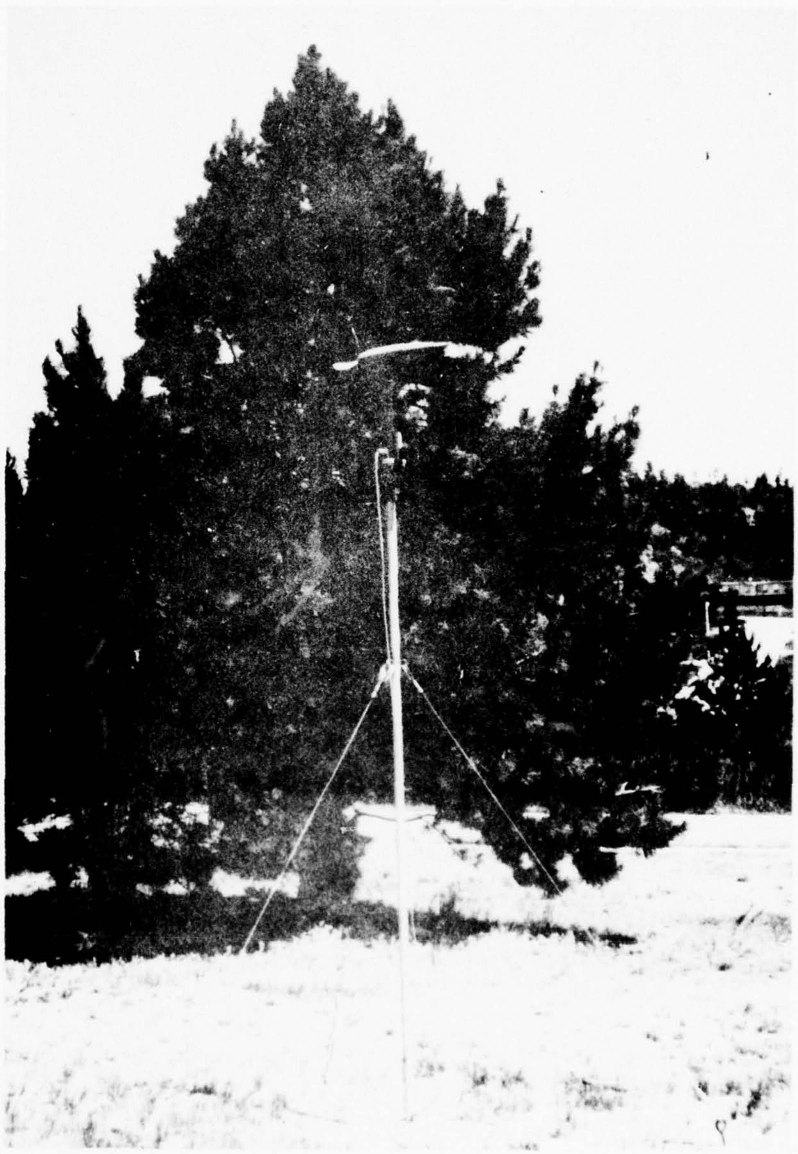


Figure 4-6. Wind Velocity and Direction Sensor

Figure 4-7. Temperature and Relative Humidity Sensor

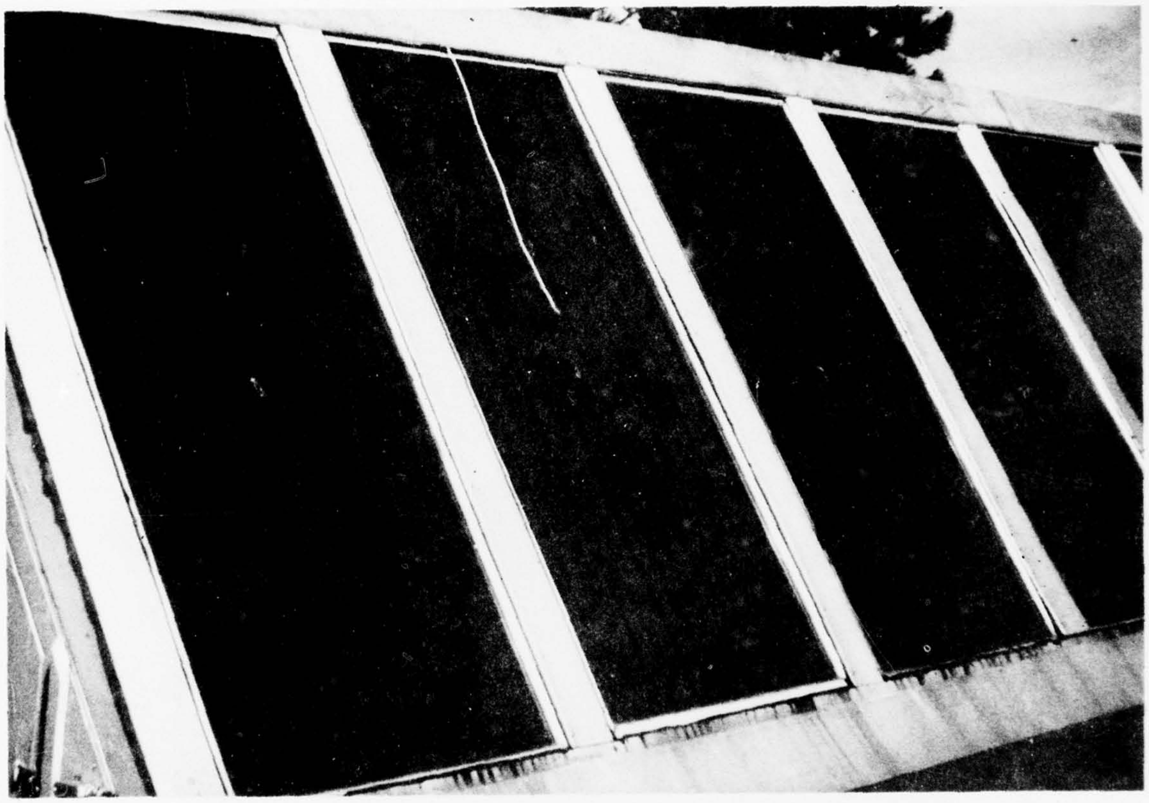


Figure 4-8. Ground Array Sensors

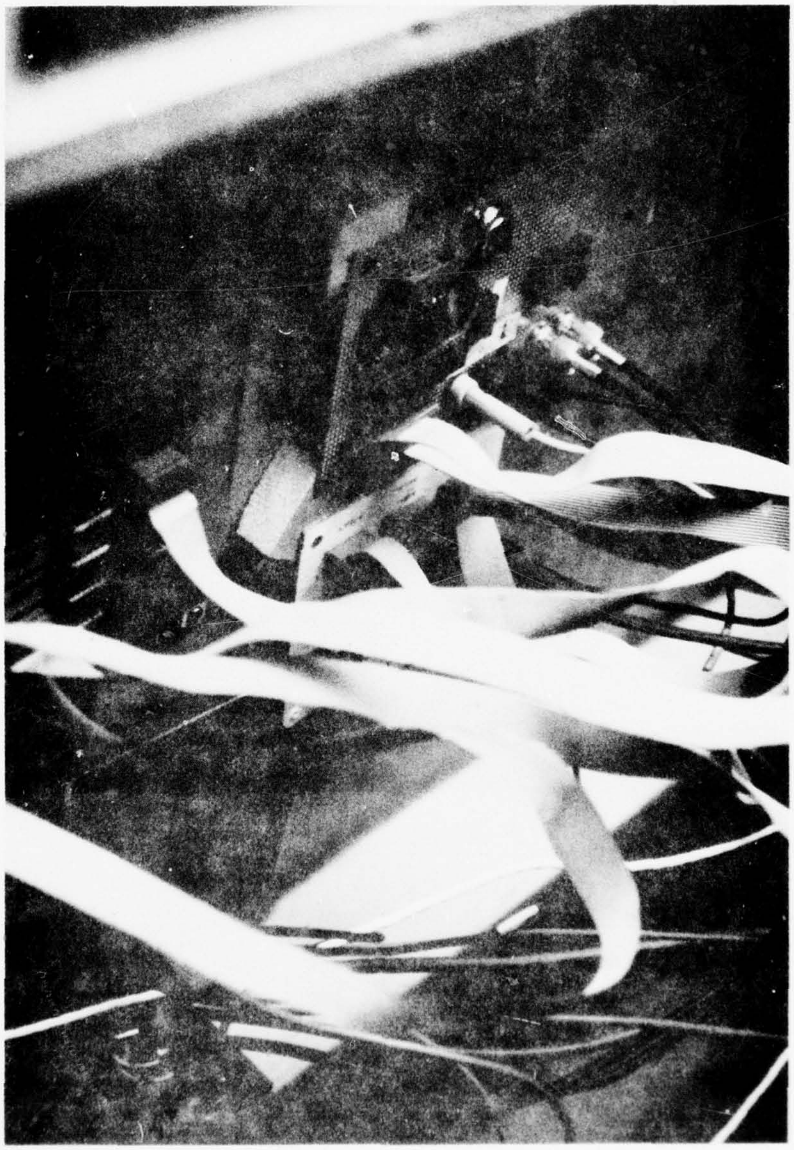


Figure 4-9. Multiplexer

CHAPTER 5

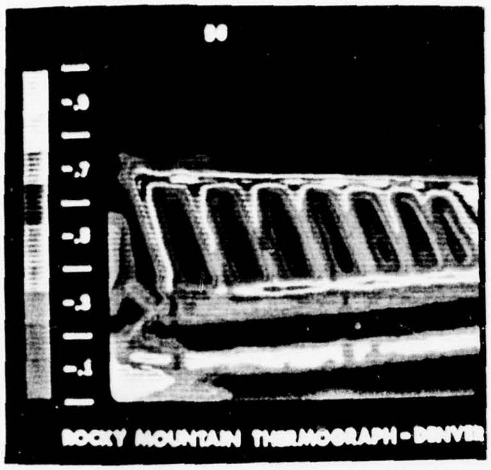
THERMOGRAPHY STUDIES

5.1 Introduction

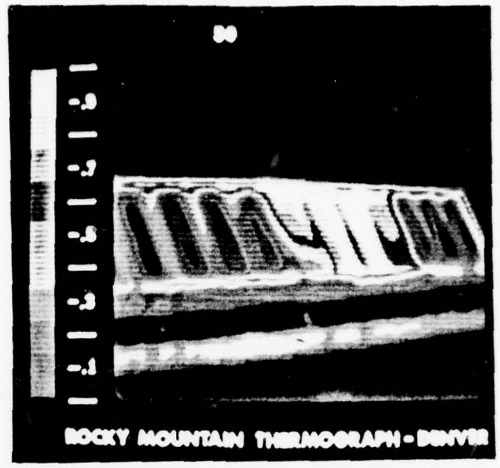
The flow patterns throughout the solar arrays have always been of great interest to the research team. The equalization of flow through the various combinations of panels in clusters of threes and fours would allow the determination of the marginal effects of the last panel of each group. Originally, sensors were not installed on all of the panels to allow measurements of the temperatures, and only the addition of sensors and the multiplexer on the ground array finally allowed this measurement to be made. However, the use of a new technique for qualitative determination of flow distribution from temperature distribution was considered through thermography. This section covers a general description of thermographic characteristics and the results obtained through correlation with the ground array multiplexed sensor readings.

5.2 Description

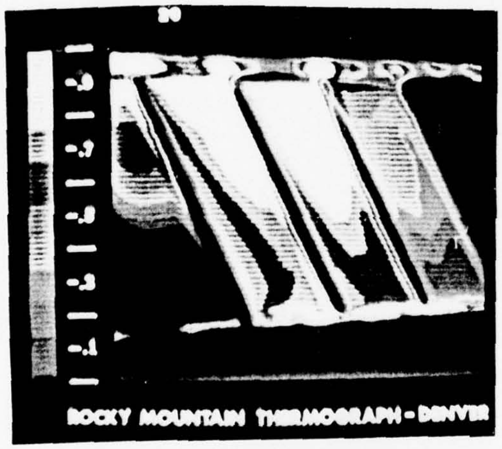
Thermography is a heat detecting technique which measures infrared radiation across the surface of a material. The temperature distribution is shown on a cathode-ray tube and then photographed to produce thermographs. The system works due to the electromagnetic radiation which all materials emit as a function of their temperature. The range of this radiation as detected by the thermographic equipment is 2.0 to 5.6 microns.



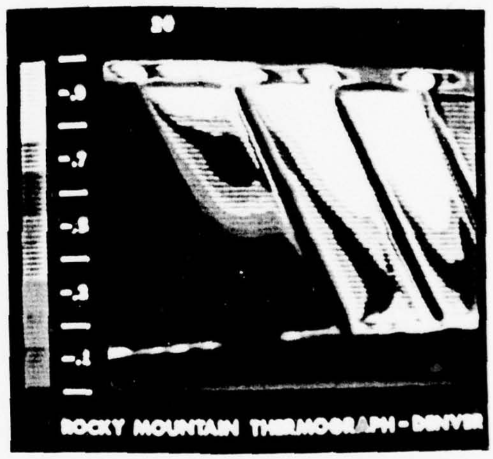
(a)



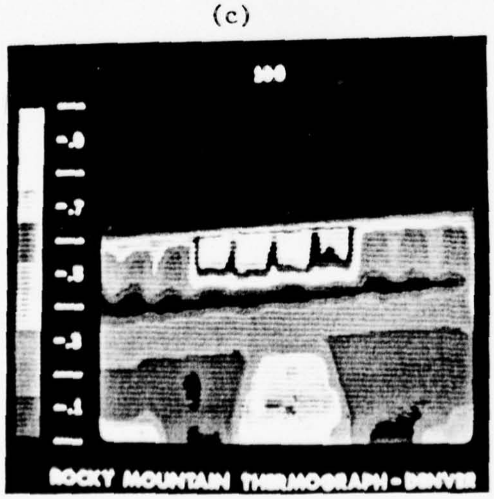
(b)



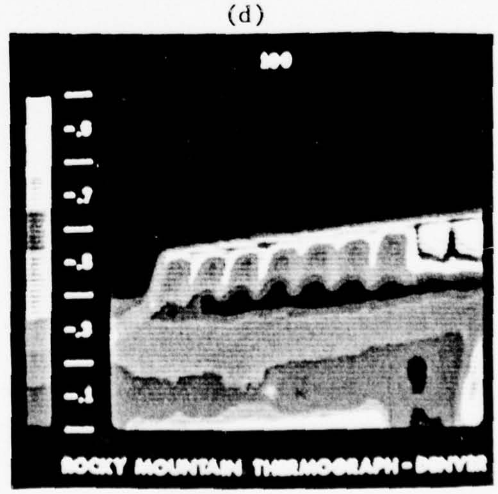
(c)



(d)



(e)



(f)

Figure 5-1 Thermography Studies

Several problem areas must be carefully considered when using thermography. Wind can affect the readings shown on the thermographs, thus a maximum wind velocity of 6.7 mps (15 mph) is recommended. Glass reflects radiation as well as emits it. If glare from the glass is present, inaccurate readings of radiation can be obtained. The glass surface of the collector was not the surface of interest but the absorber surface below was. Caution had to be used to realize that the readings were from the glass itself, and may not exactly indicate the temperature below. Since qualitative analysis was the aim of these studies, this discrepancy was taken into account.

Finally, since the radiation was from the glass, correlation was necessary to interpret accurately the thermograph readings. The multiplexer on the ground array permitted this correlation by transmitting to the microprocessor the temperature readings on all 14 panels when each thermograph was taken.

The thermographs are shown in Figures 5-1a to 5-1f. The interpretation of these pictures is relative in nature. The number at the top designates the maximum range of the temperature scale at the left of each picture. For example, 50 represents 50^{o}C (90^{o}F) and shows that the range of 0.0 to 1.0 represents a relative difference in temperature of that amount. This allows comparison of the temperature differences of various points on the thermograph. If any temperature is known on one of the surfaces, then the others can be calculated from it. The pictures can be taken in color or black and white. The colored ones, Fig. 5-1, show more clearly

the various areas of changing temperature and proved very valuable in correlating the thermographs to the actual measured temperatures.

5.3 Results of Studies

The ground array was studied first to determine if the qualitative correlation of thermographs to sensors could be made (Fig. 5-2). Fig. 5-1a shows one of the first pictures taken and Table 5-1 the multiplexed temperature readings which were simultaneously taken. These two, when combined together, revealed some startling data.

Table 5-1

Temperatures of Ground Array (^{o}F)

Panel Position	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sensor Reading	136	136	142	149	158	165	180	255	255	255	255	139	139	138

Initially, there appeared to be a large air blockage in cluster three, the second group of four panels in series. This air blockage had stopped the flow of fluid through the entire cluster and allowed the temperature to rise well above the neighboring panels. The thermograph indicated a temperature difference of at least 50^{o}C (90^{o}F) and the sensor readings indicated a difference of at least 75^{o}F. The reading of 255^{o}F was the highest the microprocessor could indicate. The correlation of the thermograph and the sensors, therefore, was limited to qualitative in that a picture showing hotter panels actually does reflect that condition on the surfaces.

The second indication noted from the data and pictures was the apparent reversed flow in the last cluster. The temperature readings

Figure 5-2

Thermography Equipment

showed no rise in temperature left to right as would be expected with the flow from the supply line to the return. The thermograph also showed relatively little temperature rise in this last group. It seemed that the blocked third cluster was forcing a high flow of fluid into the fourth cluster. Also, the discharge from the second cluster was possibly being forced up the return line to the fourth cluster, backwards through this cluster at high velocity and then back down the supply line. This pattern would explain the lack of high temperature and the absence of a temperature rise in the fourth cluster. This set of circumstances led directly to the decision to cut the flow in half to the collector arrays. Subsequent thermography studies and temperature readings showed that a normal flow pattern and temperature distribution resulted from this change, especially on the ground array. Thus, the studies allowed the effects of flow rate throughout a cluster of panels and the whole array to be observed. This eventually could lead to a balancing technique to reach higher efficiencies.

Figures 5-1c&d illustrate the close-up view of the clogged panels. Using a smaller temperature range for the scaling factor, it was possible to observe the apparent temperature distribution across the individual panels. The first panel seemed to have some cooler fluid being forced into it from the supply line inlet at the lower left corner. The air blockage was sufficiently great to stop this flow from progressing to the top of the panel. The second and third panels are completely blocked. The fourth one has some flow

entering from the return line at the upper right-hand corner making it the coolest panel. This flow results from the high pressure existing in the fourth cluster forcing fluid into the panel. Clearly, a picture such as this would indicate to a viewer that something was wrong with the cluster and remedial action should be taken.

Figures 5-1e&f show the thermograph taken of the roof array. This array did not have sensors installed on all panels, only the second and thirteenth. The picture showed a slightly different pattern within the third cluster but basically the same problem. An apparent air blockage had stopped flow in this cluster. Qualitative correlation was only possible by the investigators climbing the roof and touching the glass surfaces. The ones indicating hot were considerably hotter than the ones indicating normal patterns. It was concluded that the air blockage problem was also present in the roof array. This problem did not decrease with the change of flow rate as did some of the problems in the ground array. The roof array has the added problem of being the highest point in its flow system while the air vent valve was located 5.5m (18 ft) below in the basement. Air naturally would be forced to the highest point, and seemed to gather in that cluster.

The final results of this study are the following. A thermograph can be used to spot problems in arrays and flow patterns if care is taken for wind velocity and reflected glare. The thermographs qualitatively indicate accurately the temperature distribution across the panels. Adjustments could be made while visually watching the effects of the balancing attempts. The effect of various flow rates

on even flow distribution could be determined by observing thermographic results rather than installing numerous sensors and multiplexers to gather the data. Maintenance could be performed by responding to certain sets of thermographic data both for prevention of problems and increased efficiency of operation.

The first thermographs also showed that the plumbing raceways were very large sources of energy losses. The lack of insulation in these areas caused much heat to be given off through the steel flashing located above the plumbing lines. The subsequent insulation of the raceways led to decreased temperatures indicated on the next series of thermographs and a cutting of the edge heat losses from the collector arrays. The same indications also led to the flexible tubing into and out of the ground array being covered with Armaflex to better insulate those areas. Subsequent thermographs also showed that the reduced flow rate did solve the air blockage problem on the ground array by apparently allowing the air to flow out of the system through the bleed air line. The thermograph still showed the roof array third cluster as blocked even with one-half flow.

CHAPTER 6

DATA ANALYSIS

6.1 Introduction

This section of the report covers the analysis of specific data gathered during the reporting period. The daily analysis section addresses actual performance on 19 March 1977. The month used in the monthly analysis section is February 1977. Yearly performance discusses all the data to date with emphasis on improvements as the project progressed. Other areas of interest are also covered to include the performance of the arrays and the consumption of natural gas and electricity.

6.2 Daily Performance

The first interim technical report covered extensively the programmed control of the solar energy systems. The actions of the microprocessor were discussed and the various control points and temperatures listed. This section will analyze in detail one day's operation of the solar energy systems in the house to show actual performance and the effects of the various parameters.

The data analysis for 19 March 1977 is shown in Fig. 6-1 for English units and Fig. 6-2 for SI units. These figures are the results of the computer program that takes the hard data from the microprocessor collection system and analyzes it using the common relationships listed in the first interim technical report. The data analysis is then listed in the format shown for the researchers

SOLAR TEST HOUSE
DATA ANALYSIS PROGRAM

```
HC BTU = 116715. (375-615)
Gas BTU = 14804. (9 at 635)
Gas BTU = 29607. (9 at 710)
Gas BTU = 44411. (9 at 750)
Tank Water Temp at Begin of RA Operation = 87 at 839
Tank Water Temp at Begin of GA Operation = 87 at 841
Gas BTU = 59215. (9 at 842)
Tank Water Temp at End of RA Operation = 87 at 845
RA BTU = 235. (6 at 845)
Tank Water Temp at End of GA Operation = 87 at 847
GA BTU =  -613. (6 at 847)
Tank Water Temp at Begin of RA Operation = 87 at 852
Tank Water Temp at Begin of GA Operation = 87 at 855
Tank Water Temp at End of RA Operation = 87 at 857
RA BTU = 653. (5 at 857)
Tank Water Temp at Begin of RA Operation = 87 at 858
Tank Water Temp at End of GA Operation = 87 at 903
GA BTU = 1709. (8 at 903)
Tank Water Temp at Begin of GA Operation = 87 at 907
Gas BTU = 74018. (9 at 958)
HC BTU = 133757. (43-1300)
HC BTU = 148619. (30-1542)
Tank Water Temp at End of GA Operation = 106 at 1603
GA BTU = 282902. (416 at 1603)
Tank Water Temp at End of RA Operation = 106 at 1616
RA BTU = 300102. (438 at 1616)
Sun BTU/SF Horiz = 1714. (705-1800)
Sun BTU/SF GA = 2136.
Sun BTU/SF RA = 2219.
HC BTU = 163877. (33-1814)
HC BTU = 181216. (35-2040)
HC BTU = 230260. (111-2345)
```

Summary of Day 78
(0 to 2345)

House BTU's:	Gas + Solar = 304279.	Solar = 230260	%Solar = 75.7
Ground BTU's:	Available = 473203.	Collected = 282902.	% Eff = 59.8
Roof BTU's:	Available = 491593.	Collected = 300102.	% Eff = 61.0

Figure 6-1. Data Analysis (English Units)

SOLAR TEST HOUSE
DATA ANALYSIS PROGRAM

```
HC MJ = 123.14 (375-615)
Gas MJ = 15.62 (9 at 635)
Gas MJ = 31.24 (9 at 710)
Gas MJ = 46.86 (9 at 750)
Tank Water Temp at Begin of RA Operation = 31 at 839
Tank Water Temp at Begin of GA Operation = 31 at 841
Gas MJ = 62.48 (9 at 842)
Tank Water Temp at End of RA Operation = 31 at 845
RA MJ =  0.  (6 at 845)
Tank Water Temp at End of GA Operation = 31 at 847
GA MJ =  -0.65 (6 at 847)
Tank Water Temp at Begin of RA Operation = 31 at 852
Tank Water Temp at Begin of GA Operation = 31 at 855
Tank Water Temp at End of RA Operation = 31 at 857
RA MJ = 1. (5 at 857)
Tank Water Temp at Begin of RA Operation = 31 at 858
Tank Water Temp at End of GA Operation = 31 at 903
GA MJ = 1.80 (8 at 903)
Tank Water Temp at Begin of GA Operation = 31 at 907
Gas MJ = 78.09 (9 at 958)
HC MJ = 141.12 (43-1300)
HC MJ = 156.80 (30-1542)
Tank Water Temp at End of GA Operation = 41 at 1603
GA MJ = 298.48 (416 at 1603)
Tank Water Temp at End of RA Operation = 41 at 1616
RA MJ = 317.  (438 at 1616)
Sun MJ/SM Horiz = 19.47 (705-1800)
Sun MJ/SM GA = 24.26
Sun MJ/SM RA = 25.20
HC MJ = 172.90 (33-1814)
HC MJ = 191.19 (35-2040)
HC MJ = 242.94 (111-2345)
```

Summary of Day 78
(0 to 2345)

House MJ's:	Gas + Solar = 321.03	Solar = 242.94	%Solar = 75.7
Ground MJ's:	Available = 499.26	Collected = 298.48	%Eff = 59.8
Roof MJ's:	Available = 518.66	Collected = 316.63	%Eff = 61.0

Figure 6-2. Data Analysis (SI Units)

to further utilize for modifications of the operations or further analysis of specific moments during the day. If the data analysis appeared very interesting or unusual, a plotting procedure could be used on the computer to produce plots such as Figures 6-3, 6-4 and 6-5. For this discussion, both the listed results and the plots are referenced.

The early morning hours of this day were characterized by a need for heat in the house. With the storage tank at 34^{o}C (94^{o}F), the microprocessor selected solar energy as the source of the house heating energy. This would have continued for as long as the storage tank remained above 32^{o}C (90^{o}F). However, the control algorithm for selection of the source of house heating energy allowed the storage tank to drop to 31^{o}C (87^{o}F) before switching to the natural gas furnace. This was due to the air being heated by the storage tank water to a high enough temperature to maintain the house at 18.8^{o}C (66^{o}F), one degree Fahrenheit below the setting of 19.4^{o}C (67^{o}F). At 0551, the house temperature finally reached 18.3^{o}C (65^{o}F), and the microprocessor turned on the natural gas furnace.

As shown in Fig. 6-3, the actual temperature in the house was very constant during the time that solar energy was used to supply the heat. When the natural gas furnace was used, the temperature became erratically controlled. The furnace overshot the desired temperature by as much as 1.1^{o}C (2^{o}F) whenever it was used. This quick response to a level higher than the desired temperature was due to the over-design built into the furnace when originally installed. The larger than necessary capacity of the furnace and

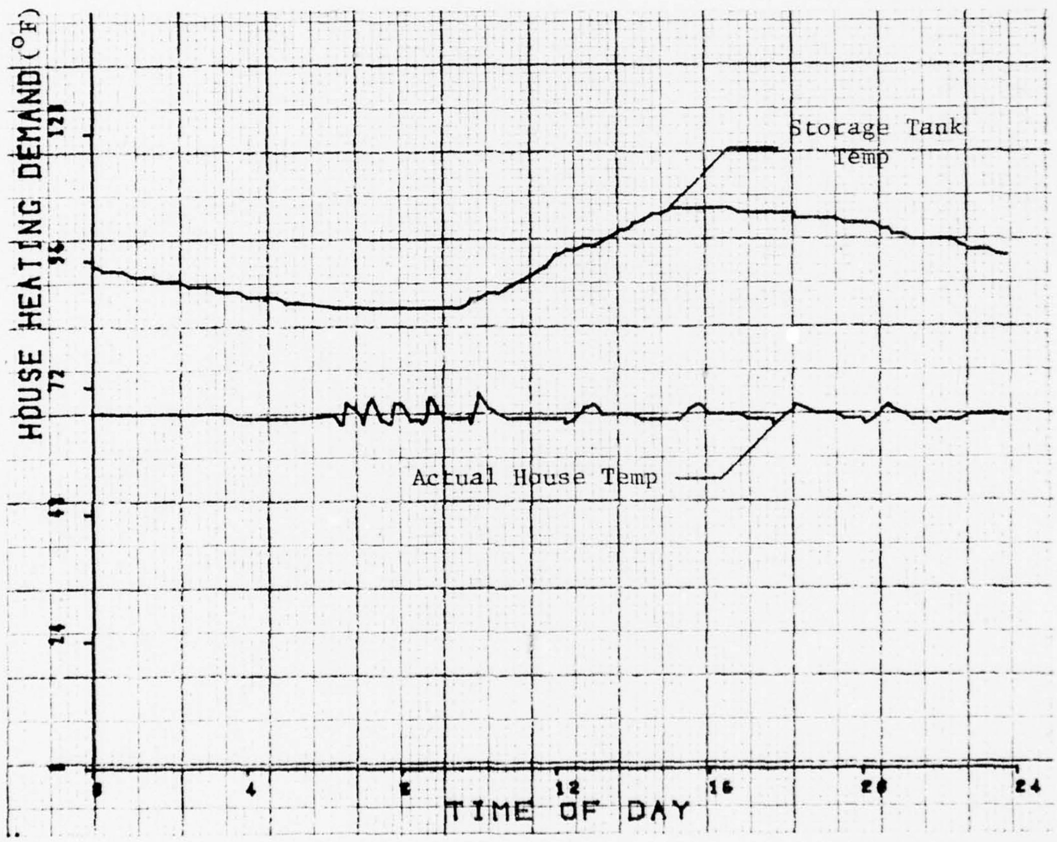


Figure 6-3

House Heating Demand Plot

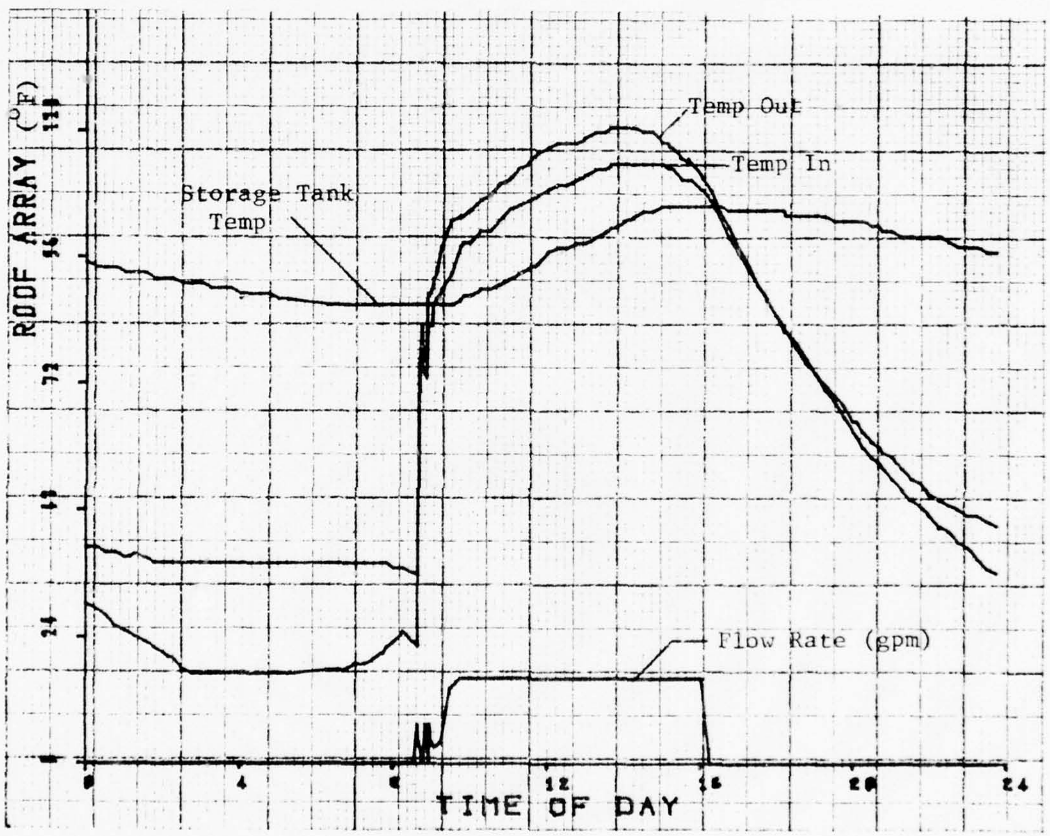


Figure 6-4

Roof Array Plot

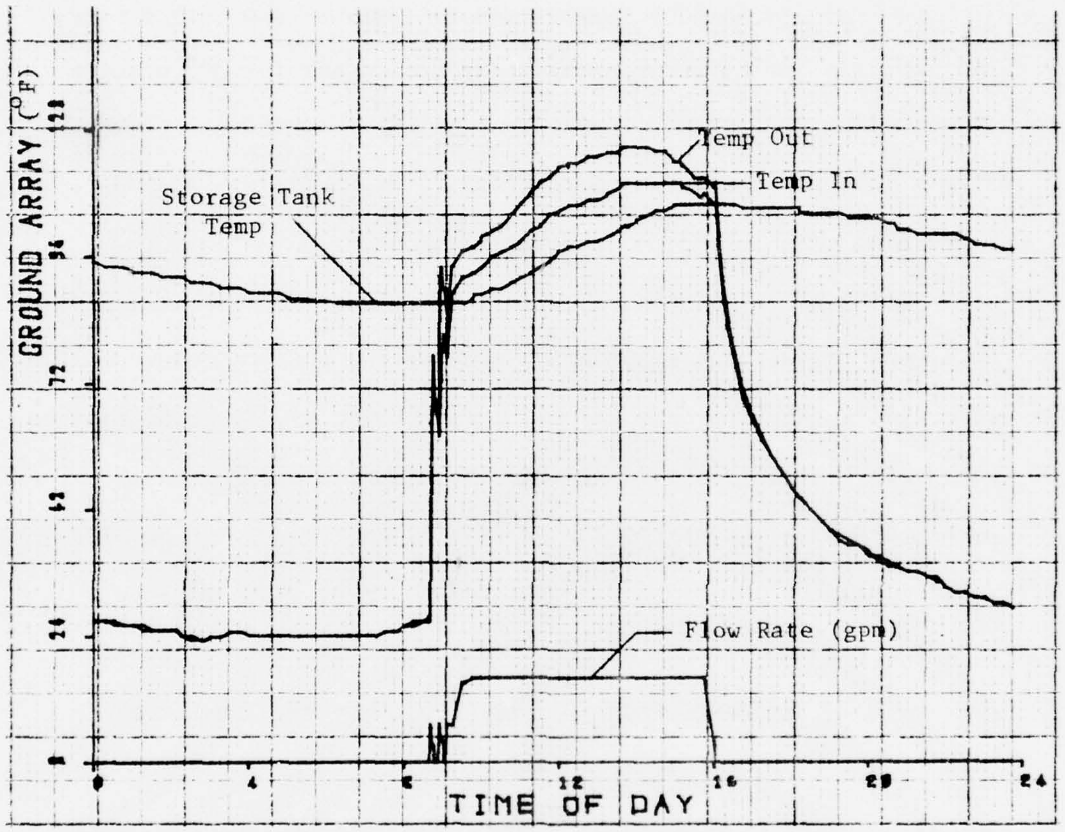


Figure 6-5

Ground Array Plot

the long lead time to start and stop it results in erratic temperature control. When solar energy was used, the temperature control was such that the desired temperature setting was met very evenly. This resulted in the fan blowing solar heated air for 375 minutes and supplying 123.14 MJ (116,717 Btu) of energy while the furnace ran a total of 45 minutes and supplied 78.09 MJ (74,018 Btu) during the morning.

During the afternoon and night, the microprocessor commanded the use of the storage tank again. Due to the collection of solar energy until 1215 the tank was hot enough, 37°C (98°F) to supply the necessary heating. The storage tank remained at a high enough temperature the rest of the day to finally supply a total of 242.94 MJ (230,260 Btu) to the house for heating (75.7% of required load).

The roof and ground arrays were both idle until about 0830. Prior to this the roof array did show a ΔT across the inlet and outlet pipes (Fig. 6-4). This was due to thermo-siphoning of the heat in the storage tank through the roof array heat exchangers up to the highest point in the system. The path from the heat exchangers in the tank to the outlet side of the roof array was direct, with the valve in that system being on the inlet side. Consequently, the hot water rises to the roof array. However, with no pumping being done, the loss was kept to a minimum. A check valve in this loop would stop this small flow.

At 0839 the roof array (RA) first attempted to collect solar energy. At this time, the surface temperature on the roof was 42°C (108°F) and the storage tank was 31°C (87°F). The microprocessor

directed the RA valve to half open and turned on the pump. For six minutes the pump ran, and finally stopped at 0845. The results were a small gain of energy of less than one MJ (235 Btu). The energy collected was at such a low temperature, with an outlet temperature of 24°C (75°F) that the results would have been an eventual lowering of the storage tank temperature if the system had continued to operate. The temperature difference was only six degrees Fahrenheit between inlet and outlet to the RA.

The ground array (GA) also attempted to function during this time, starting to pump fluid through the collectors at 0841. The slight difference between the two starting times was due to the temperature of the GA reaching 42°C (108°F) a few moments later. During this time of the year 52° was a better collector angle than 60° and this slight difference had an effect in the start-up procedure.

Two more similar attempts to start the arrays occurred shortly after the first. The surface of the panels remained higher than 11°C (20°F) above the storage tank, and the microprocessor continued to attempt to gather the solar energy. However, not until 0858 for the RA and 0907 for the GA did the systems finally come on to stay. At that point, the roof surface temperature was 46°C (115°F) and the ground was 42°C (108°F). Both arrays then started to function at full flow, approximately 60.6 lpm (16 gpm).

The RA temperature difference between inlet and outlet continued to increase to a maximum of 4.4°C (8°F) by 1145. During most of the operating period, the temperature difference was 3.9°C (7°F).

After 1445, the difference slowly decreased to eventually reach zero. The GA temperature difference increased to $4.4^{o}C$ by 1200, but fell quickly back down to $3.9^{o}C$ or less during most of the collecting period. The maximum temperature in the RA collection loop during the day was $49^{o}C$ ($121^{o}F$) reached at 1340, and the GA maximum was $47^{o}C$ ($117^{o}F$) also at that time.

As both arrays continued to function at full flow and with decreasing temperature rises, the storage tank temperature was rising to a maximum of $41^{o}C$ ($106^{o}F$) by 1500. By this time, the arrays had begun to cool down, and the solar energy collection rate dropped. The two loops' outlet temperatures began to more closely match that of the storage tank. By 1600, the GA outlet temperature had decreased to $41^{o}C$ ($106^{o}F$) and shutdown began. By 1603, the shutdown procedure was complete, resulting in 298.48 MJ (282,902 Btu) collected over a 416 minute period. The RA also shutdown shortly thereafter, stopping flow at 1616 with a total collection of 317 MJ (300,102 Btu) for 438 minutes.

The RA had run longer than the GA, and at a higher temperature. The amount of energy available to each was calculated using the insolation available from the Eppley pyranometer on a horizontal surface (Fig. 6-6), 19.47 MJ/m^2 (1741 Btu/ft^2) for 705 minutes. When converted to the slopes of the arrays, and divided into the amount of collected energy, the resulting efficiencies were 59.8% for the GA and 61.0% for the RA. Apparently the RA, with its less steep angle, was more efficient during this day in March.

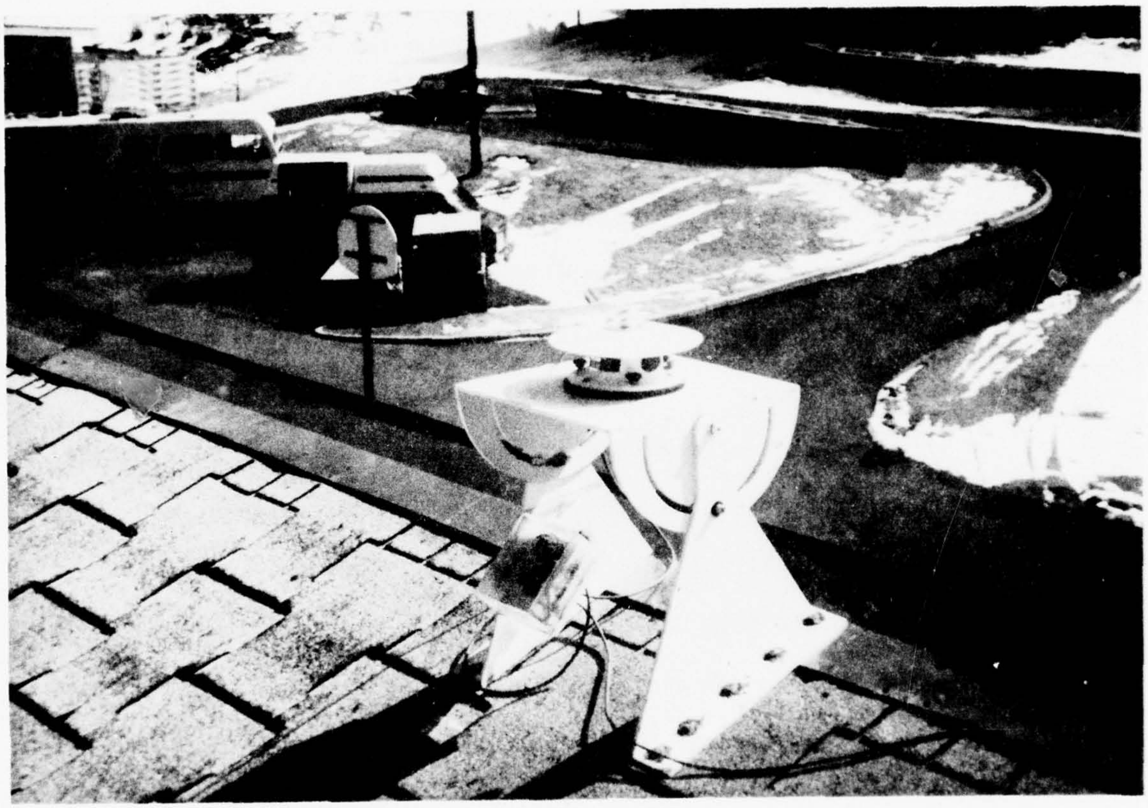


Figure 6-6

Pyranometer

Both arrays stopped collection at higher temperatures than they began the day. The energy stored in the mass of the arrays was not collected. This energy was lost due to the storage tank rising in temperature throughout the day and finally surpassing the maximum temperature of the outlets of the collectors. Also, as the day progressed, and the arrays became hotter, the collection efficiency also dropped, resulting in some energy not being recovered from the mass of the collectors. It would seem that this energy could have been recovered as the insolation level decreased, but the higher fluid temperature in the afternoon resulted in a larger temperature difference across the collector glass to the ambient temperature, and thus a lower overall collection efficiency. Throughout the early evening, the collectors cooled slowly, being poor radiators, and finally the thermo-siphoning began again on the RA about 1900. The storage tank temperature slowly decreased due to the water being used to supply the house with heat, and the final temperature was 36^{o}C (97^{o}F). This reflected a gain of energy over the day of 66.00 MJ (62,550 Btu) in the storage tank water. The final balance of energy is shown in Table 6-1. The lost energy would have to be adjusted for any used for domestic hot water. The overall efficiency of use of collected energy was 39.5%.

Table 6-1

ENERGY BALANCE

	(MJ)
Collected	+ 615.11
Used	- 242.94
Stored	- 66.00
Lost	- 306.17

6.3 Monthly Performance

The month of February 1977 was chosen as the month to be analyzed in this report due to significant changes which occurred. As is shown in Appendix B, the data for the end of this month, especially the period of 21 to 24 February, was incomplete. This was due to transient problems in the microprocessor circuitry causing the record tape to not pick up the data on 22 February and a faulty Input-Output board which needed replacement. Also, during this time, the microprocessor clock began to show signs of failure, with a broken lead on one of the components as a cause.

Fig. 6-7 is a representation of the data from this month. The house heating demand started off at the high level to be expected during the winter. A maximum of 600 MJ (568,690 Btu) was required on 8 February due to house cleaning and painting and the load decreased from there. The Degree Days for the month are shown in Fig. 6-8. On approximately 13 to 14 February, a peak in the degree days occurred. This peak was higher than the number of degree days on 8 February, and yet the house heating demand did not rise accordingly. This was the first indication of the effectiveness of the urea foam and roof insulation that had been added to the Solar Test House on 2 February. Although the weather apparently would cause the load to rise to at least the level of 500 MJ, it did not. The load during 13 and 14 February peaked at 384 MJ (363,962 Btu). Since the weather indicators were not functioning at this time, the important contribution of wind to the house heating load cannot be determined. However, using these two figures, the continued effect of urea foam is obvious.

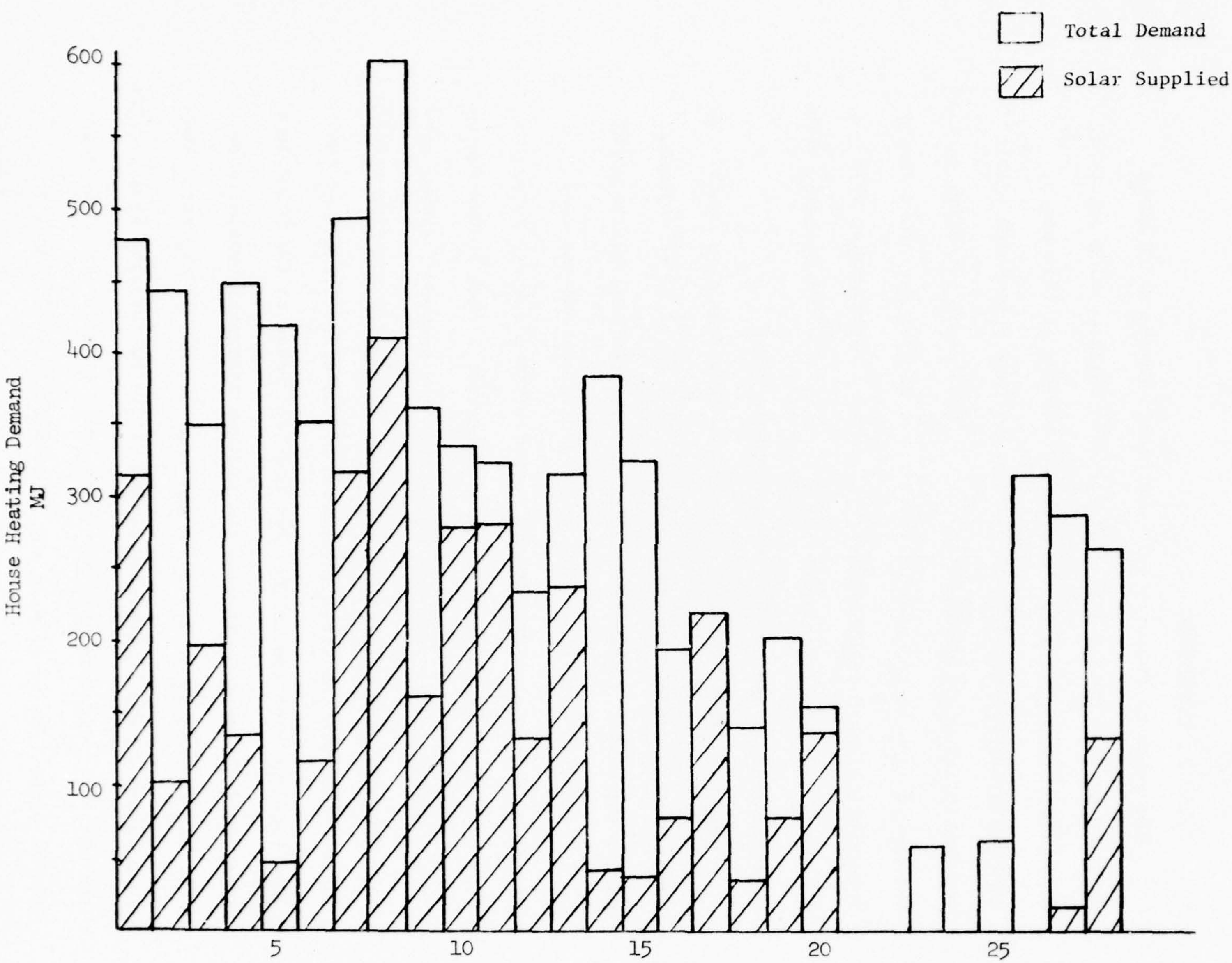


Figure 6-7. House Heating Demand

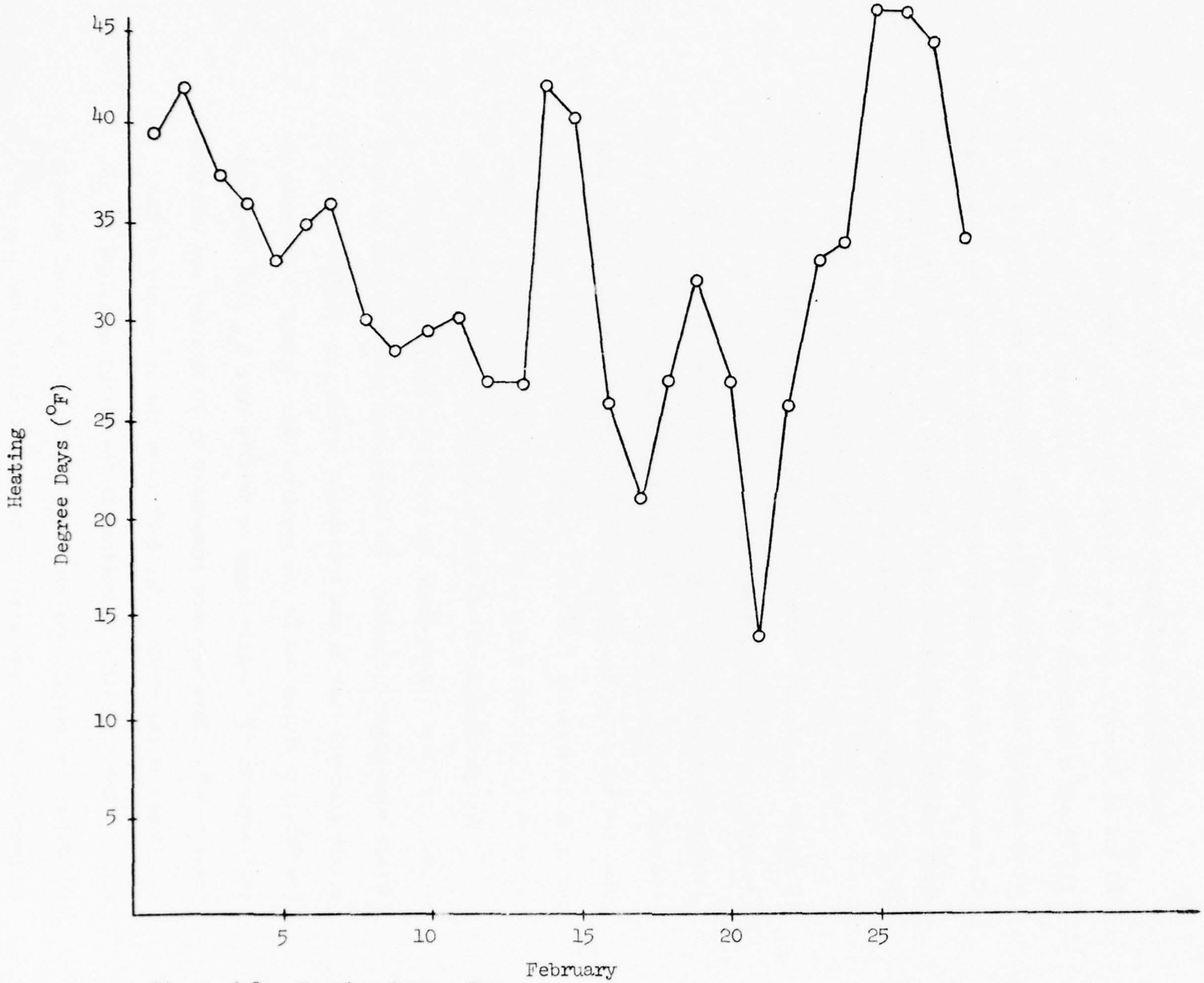


Figure 6-8. Heating Degree Days

For example, the highest degree day recording occurred on 25 and 26 February, with an average outside air temperature of $-8^{o}C$ ($18^{o}F$) and a snowstorm in progress. Yet, during this period, the house heating load did not rise above the level reached on 14 February. The added insulation's effect was direct in reducing the large load from cold air and indirect in reducing the effects of the high winds that accompanied the blizzard.

Fig. 6-7 also reflects the contribution of solar energy to the house heating load. During the month, 7,741 MJ (7,337,000 Btu) were supplied to the house and 44% was from solar energy. One day (17 February) was 100% solar energy. The effects of the lowering of the tank control to $34^{o}C$ ($94^{o}F$) and the decreased mass are apparent when the totals of the two years are compared. The energy provided by solar in February 1976 was 2,645 MJ (2,507,000 Btu) and in 1977, 3,436 MJ (3,257,000 Btu)(18,990 MJ vs 20,865 MJ available energy).

The performance of the arrays is reflected in Figure 6-9 and 6-10. The first figure shows the available energy (Q_{av}) to the arrays throughout the month. The insolation on the tilted surfaces always exceeded that on the horizontal during this period due to the low position of the sun in the southern sky. Around 17 February the roof array at 52^{o} finally began to receive more Q_{av} than the ground array at 60^{o}. This was more pronounced by 20 February and continued to the end of the month. Fig. 6-10 shows the efficiency of the arrays. The efficiency is defined as the energy collected (Q_{col}) divided by the energy available (Q_{av}). The arrays showed an early tendency for the ground array to be more efficient than the roof.

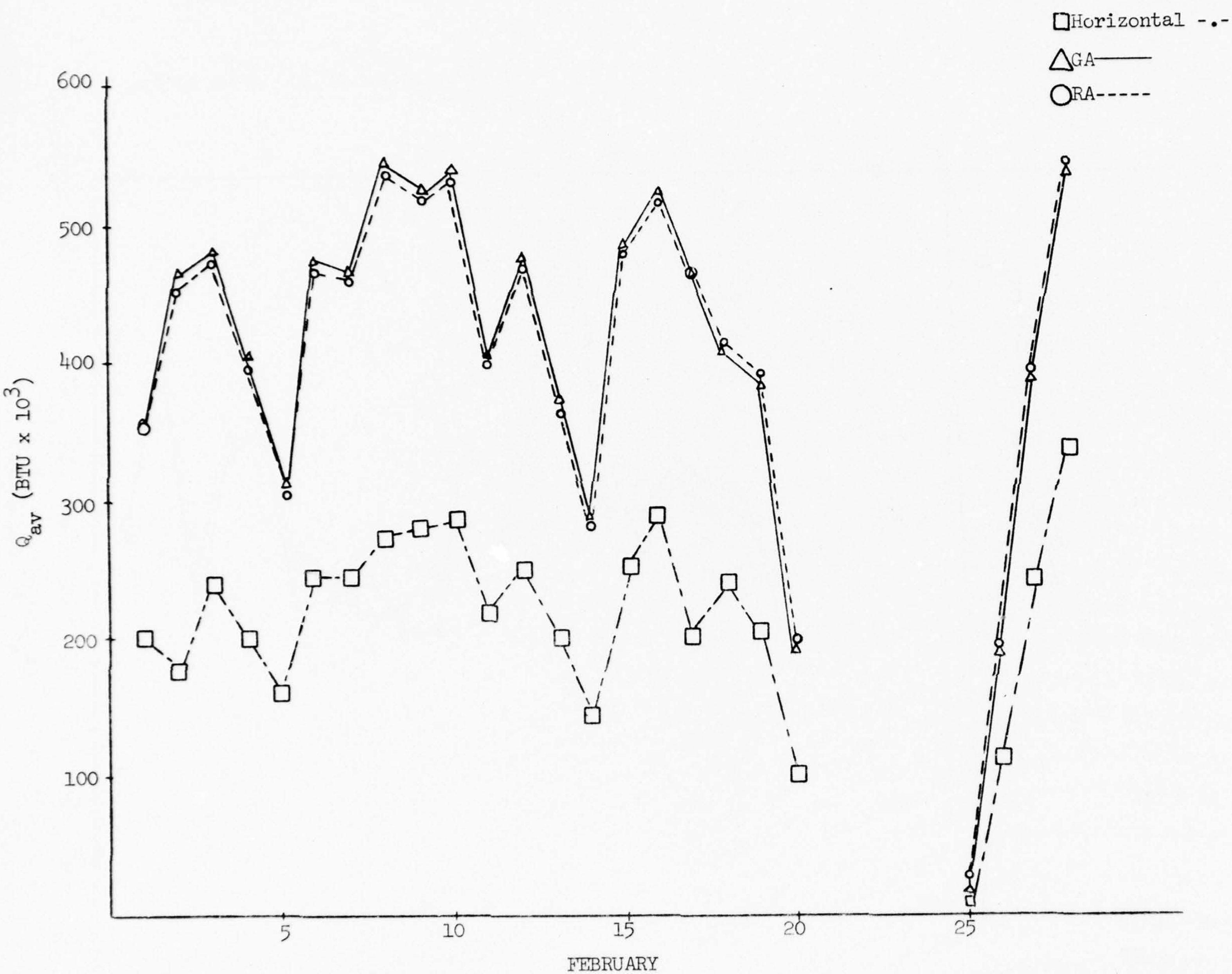


Figure 6-9. Energy Available

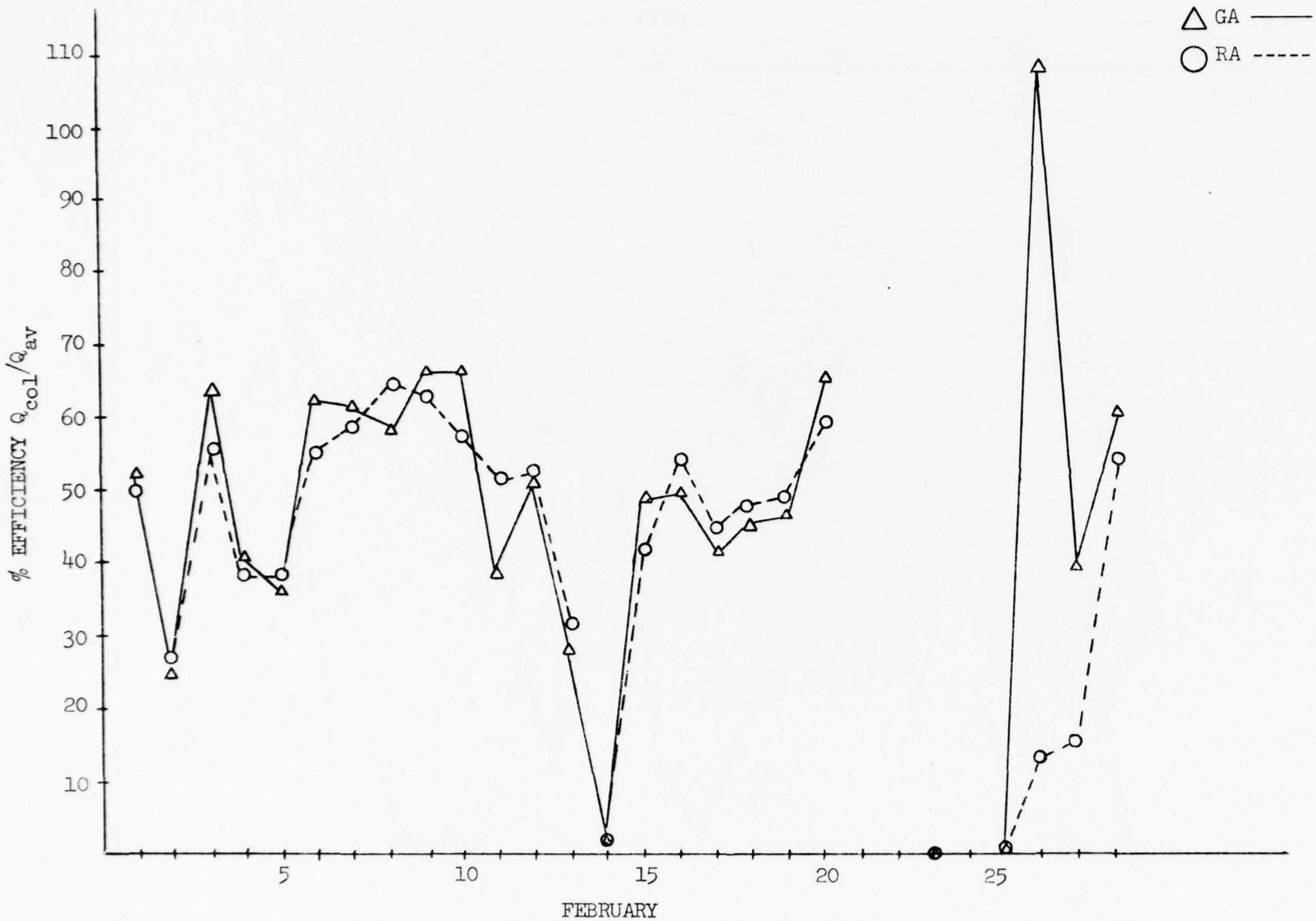


Figure 6-10. Collector Efficiency

The roof array began to show some improvement at about 16 February, but was very low from 25 to 28 February. This was the effect of snow deposited on the arrays. As discussed in the first interim technical report, the ground array will clear of snow much sooner than the roof array. Also, the pyranometer retained some snow on 26 February, blocking the sun's rays from the measurement device and explaining the 108% efficiency on that day. The direct result of snow accumulation was very poor roof array performance while the ground array was functioning normally.

The overall efficiency for the two arrays was 47%, with 9,879 MJ (9,363,758 Btu) collected out of 20,865 MJ (19,776,619 Btu) available and with the roof array slightly more efficient. The overall efficiency obtained by dividing the 3,436 MJ (3,256,238 Btu) provided to the house by Q_{av} was 16.5%.

6.4 Yearly Performance

The collection of data for the Solar Test House covers the time from December 1975 until the present. As the project began to exceed one year's operation, yearly performance could finally be examined and analyzed. The data on Figures 6-11 to 6-13 represent this time period and includes the data from the first interim technical report for comparison to later data.

Fig. 6-11 shows the heating demand experienced by the Solar Test House and the amount supplied by the solar energy system. This figure uses a furnace efficiency of 50%. The data from December 1975 and January 1976 is incomplete due to operational difficulties during those months.

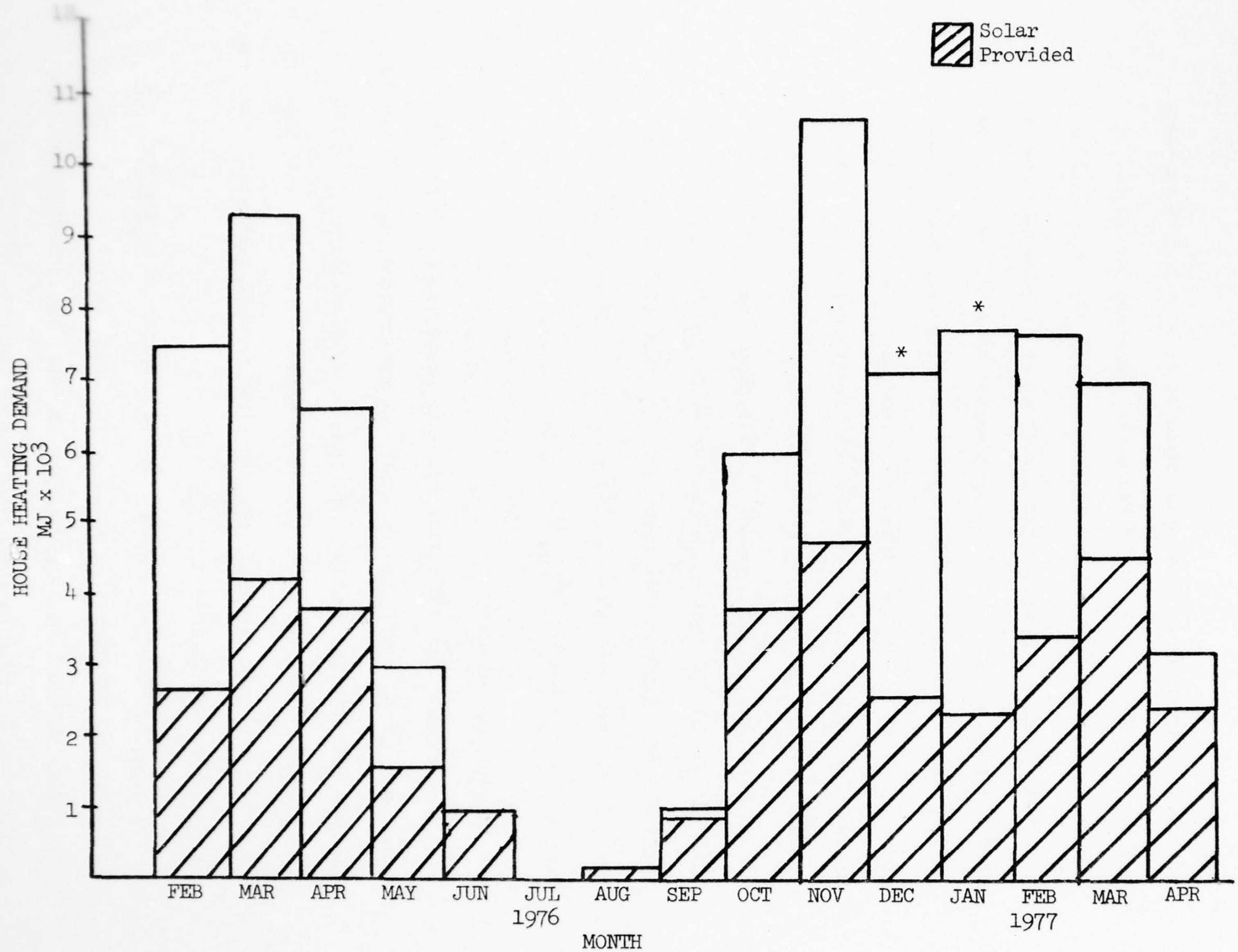


Figure 6-11. Monthly House Heating Demand

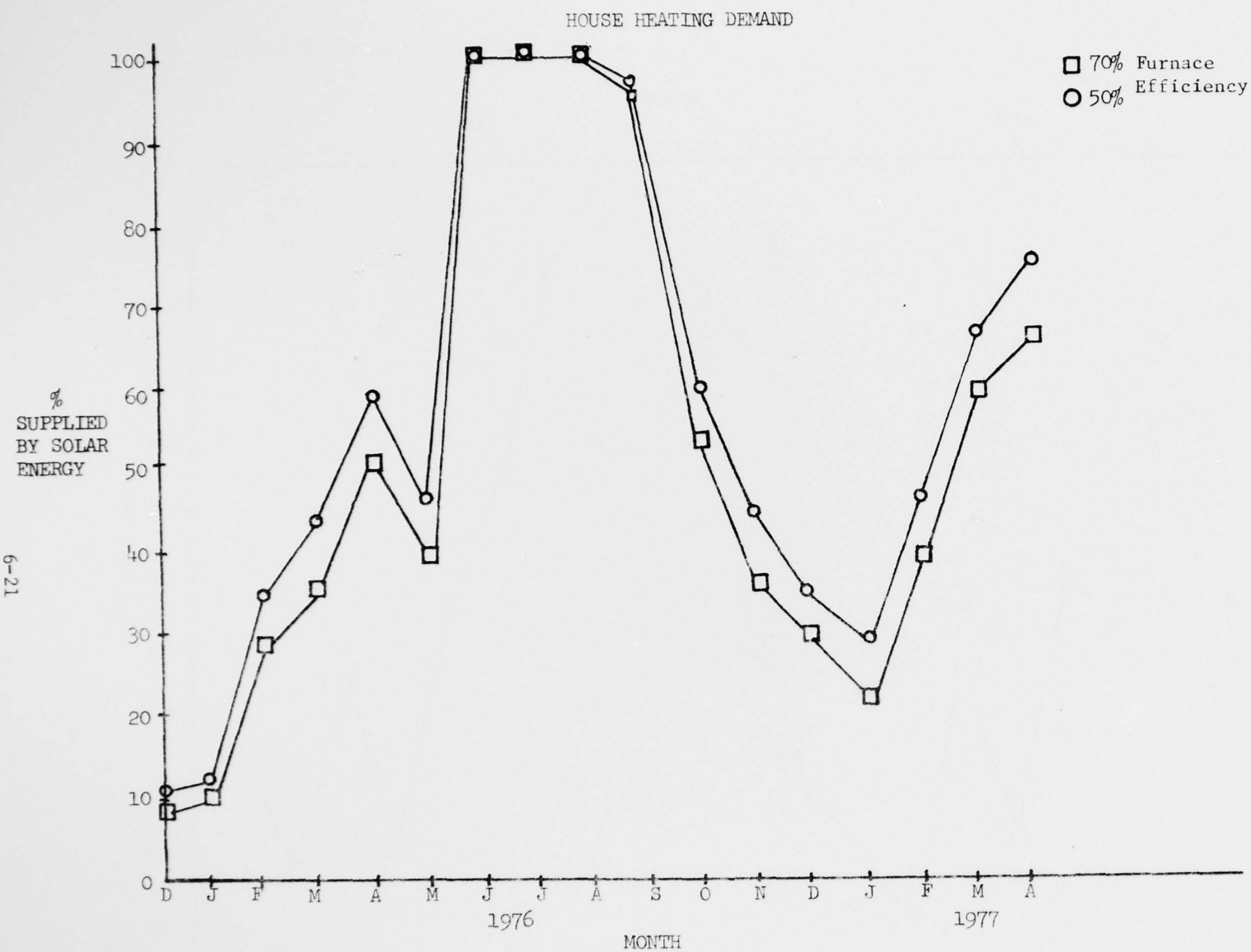


Figure 6-12. Monthly Solar Contribution

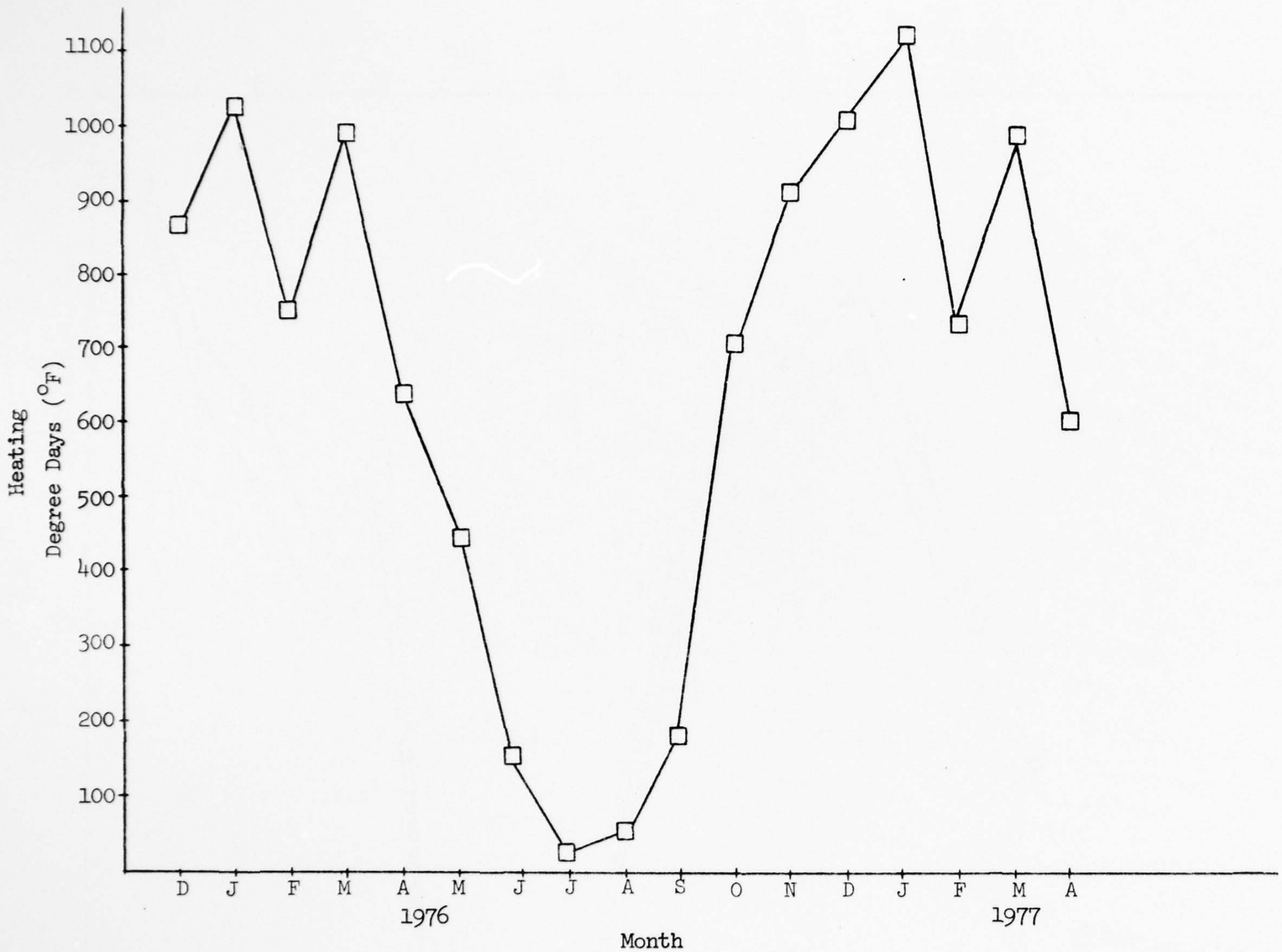


Figure 6-13. Monthly Degree Days

The first year's performance reflects the ability of the solar energy system to supply the demand under the original control system logic. The reduction of tank mass and the lowering of control temperatures became effective in December 1976 and the data first reflects this in February. Figure 6-11 and Table 6-2 both show the load this month and the subsequent improvement of the percentage of solar contribution. Fig. 6-12 clearly indicates the upward trend of improvement in the solar energy system performance from the previous year during this period and on to the present. This improvement is especially apparent when comparing the degree days of each year shown in Fig. 6-13. This figure shows that the two winter seasons were very similar in severity, with both months of March being nearly equal.

The comparison of Figures 6-11 and 6-13 shows clearly the effects of the urea foam installation in the house. As was discussed in the monthly performance section, this foam had an immediate and dramatic effect on the house heating demand. This was especially significant when the degree days of each month are compared from year to year. With both periods having nearly equal possible heat loads due to low ambient temperatures, and a reduction in actual heat load in the house, installation of urea foam proved its worth. This reduction allowed the solar energy system to operate to supply a smaller load, and directly improved overall efficiency. Table 6-3 shows that as time progressed, and the initial problems in December 1975 and January 1976 are not included, yearly performance improved to 49% of the load supplied by solar energy. A continuation of this improvement

HOUSE HEATING DEMAND

(MJ)

Month	Provided	Required 70%*		50%*	
Dec 75	657	7971	8%	5882	11%
Jan 76	678	7118	10%	5278	13%
Feb 76	2645	9365	28%	7445	36%
Mar 76	4117	11625	35%	9480	43%
Apr 76	3777	7575	50%	6490	58%
May 76	1462	3755	39%	3100	47%
Jun 76	891	895	100%	894	100%
Jul 76	-	-	-	-	-
Aug 76	50	50	100%	50	100%
Sep 76	800	853	94%	838	95%
Oct 76	3647	7020	52%	6056	60%
Nov 76	4694	13202	36%	10771	44%
Dec 76	2452	8851	28%	7029	35%
Jan 77	2114	10150	21%	7854	27%
Feb 77	3436	9465	36%	7741	44%
Mar 77	4581	7816	59%	6892	66%
Apr 77	2226	3343	67%	3024	74%

*Furnace Efficiency

Table 6-2. Monthly House Heating Demand

HOUSE HEATING DEMAND
TOTALS
(MJ)

Solar Provided	Total Requirements (70%)*	Total Requirements (50%)*
December 1975 - November 1976		
23,418	69,429	56,291
	34%	42%
February 1976 - January 1977		
26,649	73,341	60,014
	36%	44%
April 1976 - March 1977		
27,904	69,632	57,722
	40%	48%
May 1976 - April 1977		
26,353	65,400	54,256
	40%	49%

*Furnace Efficiency

Table 6-3. Yearly House Heating Demand Totals

through to the summer months is anticipated with May 1977 performance reaching 100% one month earlier than May 1976. The decreased performance experienced in May of 1976 was a result of various system problems which will be discussed later.

The energy available to the collectors and the solar panels performance for the project time period is shown in Figures 6-14 and 6-15. This performance started at a lower level during initial operations but eventually settled at a level between 50% and 60%. The apparent dip in performance in October 1976 was due to a failure in the pyranometer amplifier circuit and its subsequent replacement. The overall efficiency from March 1976 to April 1977, exclusive of this dip in October, was 55%. The differences between the two arrays were often very slight, with the crossover points being discovered for the various angles and discussed elsewhere in this report. In general the ground and roof arrays performed as expected, with a subtle surprise during the summer. This period of hot weather saw a decrease in the efficiency of the roof array as compared to the ground array. This was due to the higher temperatures that existed in the collection loop of the roof array. One cause of this was the fact that the roof array was separated from the attic of the house by only one sheet of plywood paneling. The higher temperatures in the attic transmitted into the back of the solar panels and raised their surface temperatures. The higher surface temperatures immediately resulted in reduced collector efficiency. This may be one disadvantage of mounting collectors onto a roof without insulation behind them or without a way to vent the hot air out of the roof during the summer.

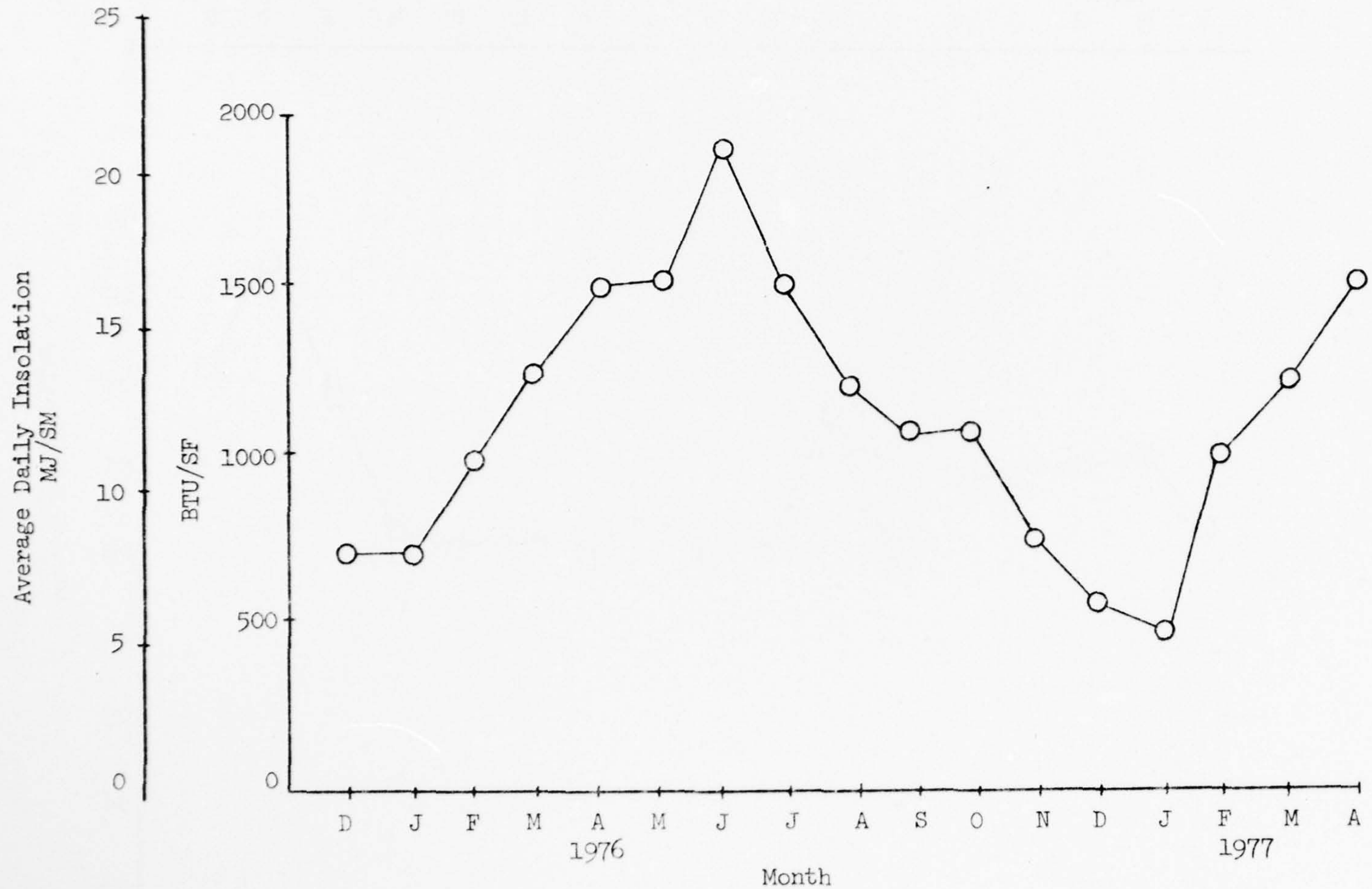


Figure 6-14. Monthly Energy Available (Horizontal)

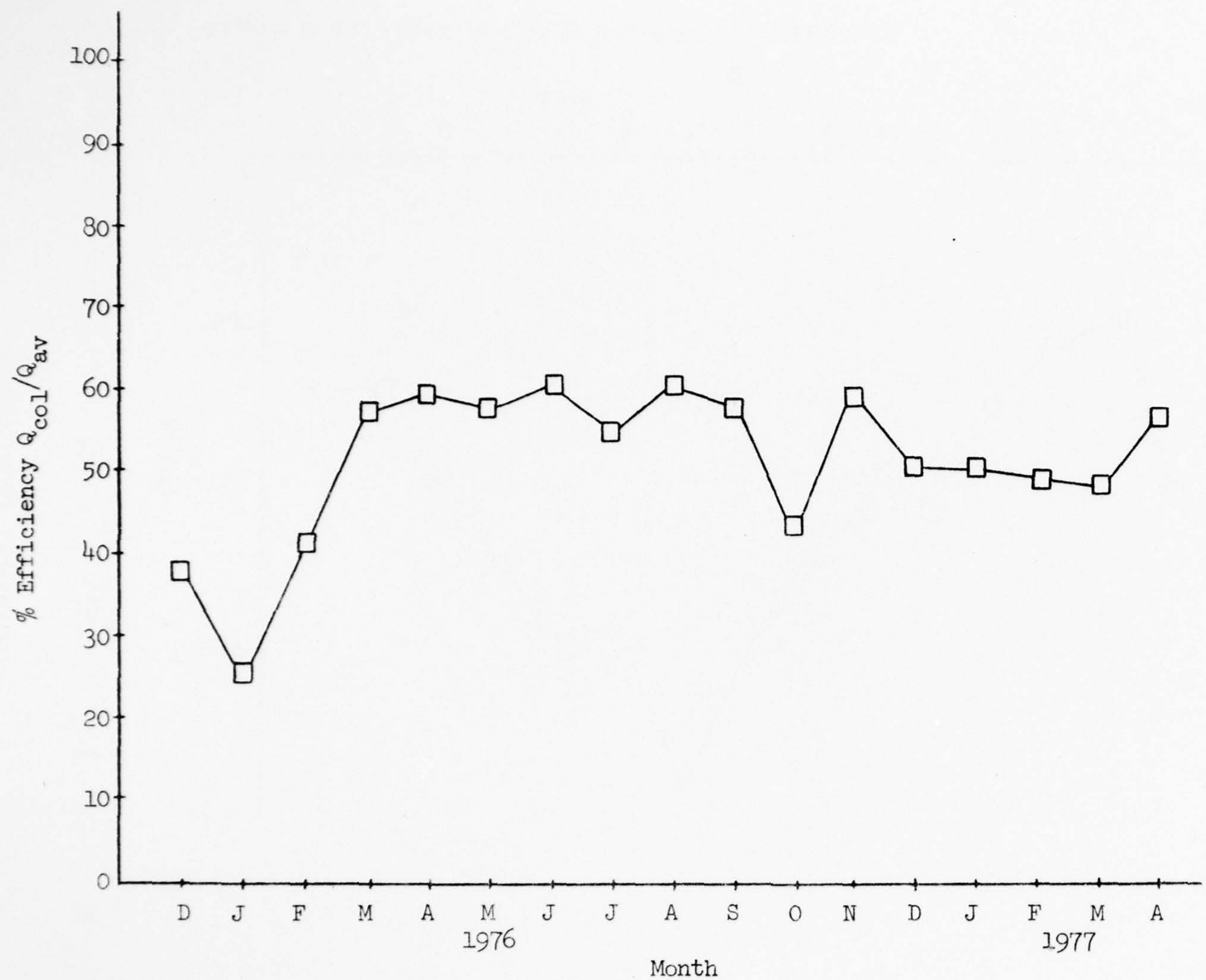


Figure 6-15. Monthly Collector Efficiency

A second reason for slightly less performance efficiency for the roof array was its greater tendency to air blockage. Again, this problem tended to manifest itself in lowered performance by not allowing the collection fluid access to a significant area of the absorbing surface. The effective area of collection was cut and the roof array efficiency suffered. Its tendency to have this problem more than the ground array was directly related to the height of the roof panels in that loop versus the height of the ground panels when compared to the pump and original bleed air valve positions.

6.5 Problem Areas

During the operation of the solar energy system over this time period, numerous problem areas were encountered and solutions attempted. The start up period was characterized by microprocessor checkout and control program verification. This would occur with almost any new system until the initial "bugs" were worked out. The original system of paper tape being produced every 15 minutes to record the data was prone to jamming due to the tape drying up the lubriant or the tiny dots becoming stuck in the gearing of the punch. The reliance of the control system in the various temperature sensors dictated erratic operations if the sensors should fail. The most critical sensor became the tank sensor. This was due to its function in the control loop for the start up procedure, the hourly running of the system, and the use of solar energy in the storage tank to supply the house heating demand. This sensor failed numerous times due to direct immersion in the storage tank water. The water would work its way

into the wiring and short-circuit the sensor circuit. The final fix of the annoying problem was the enclosure of the sensor in a copper pipe which was capped at the lower end. The upper end was packed with dehydrant and sealed with silcon gel. This arrangement stopped sensor failure at the slight sacrifice of less than absolute accuracy of temperature readings due to the conduction of copper rather than direct immersion.

The overriding problem of air blockage continued through to April 1977. Once a block occurred detection was often indirect. A decrease in efficiency was a good indication, but that only became apparent after analysis of the data sometime later. Feeling the panels was another detection process which was easily done on the ground array but not so on the roof. Noticing that the array surface temperatures were elevated more than normally (during the day) was another method of detection but this only worked if the blockage happened in cluster one or four where the sensors were located. The installation of the multiplexer and sensors solved this problem on the ground array. Air bubble sounds in the array plumbing was still another method as was the observation of elevated pressures during operation of the collection system. Once observed, the only correction procedure was to take off the flashing at the top of the array and attach the small, submersible pump at the end of the return line under cluster four. A bucket of collection fluid was used to supply makeup fluid and each panel was individually charged by opening the petcock at the top. This procedure took about one hour for each array. An automatic changing system is therefore being explored

presently to allow automatic air bleeding and recharge wherever system pressure drops below a preset level.

The variable valve electronics system caused difficulty in determining the actual flow rate directly for analysis purposes. Since the original plan had called for electronic reading of the flow rate through Pottermeters and since this system had never been installed, flow rate based on valve position was the only way to relay that information to the analysis program. The valve developed some slack in the linkage such that the selection by the microprocessor of a certain signal did not necessarily translate to the exact desired flow rate. This problem usually showed up in analysis of the data and a sudden increase in panel efficiency. If the mechanism for controlling the valve position overran its stops, the valve became 180^{o} out of sequence and opened fully at night. This was observed either directly by the resident engineer or indirectly by observing the high roof array temperatures due to thermal siphoning. Other problems evolved if the electrical circuit became slightly out of adjustment. Consequently, the variable flow rate function caused numerous repairs to be made and one rewiring of the system had to be accomplished. It has not been determined if the variable option has proven economically advantageous due to these problems. It does allow extra energy to be collected during marginal conditions, and could allow computer control to set various controlling strategies, but these problems have made the research team members wary of attempting too many changes until

further repairs are made to correct the variable nature of the valve control response to microprocessor instructions.

6.6 Natural Gas and Electricity Consumption

The consumption of natural gas to heat the house, supply the domestic hot water (DHW) and cook the food was metered throughout this test period. The meters used were standard gas company residential meters which were calibrated by the local gas company during January 1977. The control house (CH) data became important at this point for the comparison of its consumption to that of the Solar Test House (STH). The data is listed in Appendix C and summarized in Table 6-4.

Correlation of the CH to the STH for determination of savings was very difficult. The original family in the STH added one member in June 1976, and this was reflected in greatly increased natural gas conusmption for DHW. The two families did not maintain very similar lifestyles and such things as house guests or leave made differences in the consumption rate. For purposes of comparison, therefore, the natural gas totals must be viewed in the light of dissimilar occupants and habit patterns.

Table 6-4 shows the savings realized by the use of solar energy for the STH thermal loads. The contribution of 36% of the total load is very significant considering the previously mentioned differences in the size and types of families involved plus the constant tours occurring at the STH. The DHW total was very low at 20%. This led to a test to determine the amount of natural gas used for the pilot light, which was measured at 25 cubic feet per day.

This natural gas usage was just to keep the tank mass at the present storage level temperature. Another test was conducted to determine the efficiency of the furnace. The initial results indicated an efficiency of converting the 0.84 MJ (795 Btu) available from each cubic foot of gas to heat into the the outlet ducts at 65%. The local gas company and other researchers in solar energy in the area use an efficiency of 50% for a new furnace. Since the ones in the houses were installed in 1959, the efficiency used for the project was assumed at 50%, with a range shown on some figures to 70%.

The electrical consumption of the STH is also listed in Appendix C by totals measured for each of the major components: the fan, and the four pumps. The total consumption of electricity to power the solar energy systems was 4751.6 KWH from March 1976 to April 1977. Since the fan would have been used to provide the house heating even with all natural gas, the consumption without it was 3288.7 KWH. The energy delivered by the solar energy system during this time was 42,333 MJ including the figure of 8086 MJ (7,663,800 Btu) for 9640 cubic feet of natural gas for DHW. The ratio of MJ/KWH was 12.87 and 12,200 for Btu/KWH.

Table 6-4. NATURAL GAS SAVINGS (FT^3)

	Total	HHD	DHW
CH*	247,820	189,950	49200
STH	159,750	112,440	39560
Savings	88,070	77,510	9640
%	36	41	20

*CH does not include January 1977

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SECOND INTERIM TECHNICAL REPORT ON USAFA SOLAR TEST HOUSE.(U)
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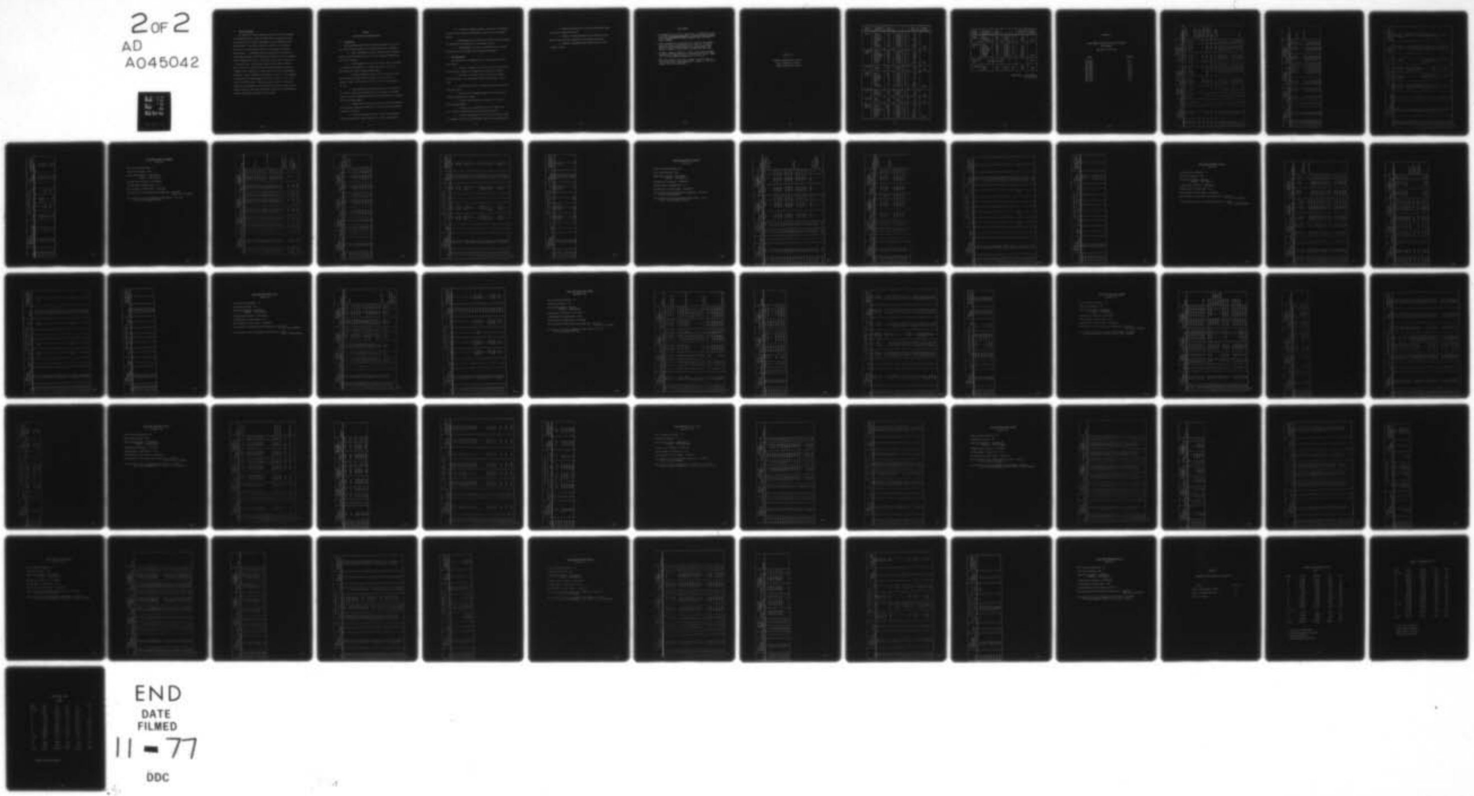

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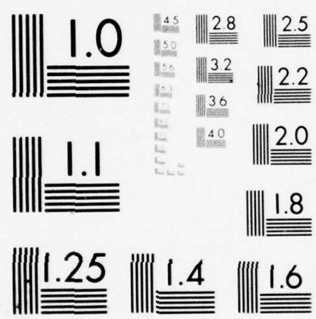

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6.7 Overall Analysis

The system as a whole actually functioned rather well during this reporting period. When left alone and not varied too often, the system ran at a level of performance a normal homeowner would have expected. There were occasional leaks due to the thermal stresses in the solder joints and the air blockage problem was always present. A homeowner could have maintained this system by occasionally feeling for the blocks and bleeding the air if necessary while recharging the fluid. An automatic system would relieve him of even that task. Once running, the system's automatic control leaves little to do but oil the pumps and check general conditions. A simpler valve installed in a home would solve the valve mechanical problem at a small reduction of some energy collection. The changing of the ground array angle appears to be only necessary twice a year, from 45° to 60° and back. Thus, this system, without the research capability and variability, proved reliable and very feasible overall. Problem areas were noted and corrections proposed with implementation already accomplished or planned for the future.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The conclusions drawn from the experience gained on this project and the data analyzed by the researchers are the following:

a. Yearly performance improved throughout this reporting period to reach a maximum of 49% of the house heating demand being met by solar energy.

b. Air blockage in the collector arrays caused a decrease in collection efficiency due to restricting the fluid flow and increasing the collector surface temperatures.

c. Collector slopes affected collection efficiency with 60^{o} being more efficient than 52^{o} during the early winter. A collector slope of 45^{o} was more efficient than 52^{o} during most of the year.

d. Decreasing the storage tank water mass and lowering the control temperature increased the time the energy in the tank could be used and increased the overall solar contribution to meeting the house heating demand.

e. Slowing the flow rate through the collectors increased returning water temperature entering the storage tank but decreased collection efficiency.

f. The faster shutdown procedure saved energy normally lost during periods of lower insolation and colder temperatures.

g. Urea foam, ceiling insulation, window panel insulation, and crawl space insulation dramatically reduced the house heating demand.

h. Thermographs of the ground array qualitatively indicated the temperature distributions of the absorber surface.

i. Thermography can be used to determine solar collector flow patterns, air blockages, and balancing requirements.

7.2 Recommendations

The following are recommendations for continued research on this project:

a. Continue to monitor the effects of the various system and operational changes for comparison to previous performance.

b. Determine the overall effects on the solar energy system efficiency from the energy conservation techniques used to date.

c. Determine the effects of further reducing the storage tank water mass.

d. Solve the air blockage problem on the roof array by installing additional air vents.

e. Install triple glazing to determine its effect on house heating demand.

f. Install a new sensing system for the domestic hot water system to determine the solar energy contribution.

g. Install flow meters on the collector fluid flow loops to determine the rate by microprocessor input and computer analysis.

h. Determine the effects of roof array and ground array location by placing both at 52^{o}.

i. Install a second generation solar collector on the ground array for direct comparison to the present collectors.

j. Install an automatic makeup water system for the collector arrays.

BIBLIOGRAPHY

1. Nay, Marshall W. Jr., Jon M. Davis, Roy L. Schmiesing, William A. Tolbert, Solar Heating Retrofit of Military Family Housing, FJSRL Technical Report 76-0008, September 1976, Air Force Systems Command.

2. Simon, Frederick F., "Flat-Plate Solar-Collector Performance Evaluation with a Solar Simulator as a Basis for Collector Selection and Performance Prediction", Solar Energy, 1976, Volume 18, Number 5, pp.451-466, Pergamon Press, New York.

3. Schipper, Thomas C. and David E. Slack, "Evaluation of Energy Conservation Methods Applied to the USAFA Solar House", DFCEM, U.S. Air Force Academy, December 1976, unpublished.

4. Mansfield, Robert G. and John D. Fouser, "United States Air Force Academy Solar House Experiments", DFCEM, U.S. Air Force Academy, May 1977, unpublished.

APPENDIX A

REVISED CALCULATED HEAT LOSS FOR TYPE 12 QUARTERS (INCLUDES ENERGY CONSERVATION CHANGES)

Room/ Space	Structural Component	Area Crack L	U	ΔT	Heat Load (Btu/Hr)	Totals (Btu/Hr)
Entry	Floor	44	0.070	50	155	
	Ceiling	44	0.029	72	92	
	B&B Wall	6	0.064	72	27	
	Glazing	56	0.560	72	2258	
	Panels	0	0.300	72	0	
	Door	21	0.330	72	499	
	$Infilt_D$	20	1.000	72	1440	
	$Infilt_W$	42	0.500	72	1512	5983
Living Room	Floor	270	0.070	50	950	
	Ceiling	270	0.029	72	563	
	Brick Wall	132	0.051	72	483	
	B&B Wall	128	0.064	72	590	
	Glazing	84	0.560	72	3387	
	Panels	0	0.300	72	0	
	Infilt	63	0.500	72	2268	8241
Kitchen	Floor	104	0.070	50	366	
	Ceiling	104	0.029	72	217	583
Dining Room	Floor	104	0.070	50	366	
	Ceiling	104	0.029	72	217	
	B&B Wall	16	0.064	72	74	
	Glazing	56	0.560	72	2258	
	Panels	0	0.300	72	0	
	Door	17	0.330	72	404	
	$Infilt_D$	17	1.000	72	1224	
	$Infilt_W$	42	0.500	72	1512	6055
Bath #1	Floor	40	0.070	0	0	
	Ceiling	40	0.029	72	84	
	B&B Wall	40	0.064	72	185	269
Bath #2	Floor	40	0.310	0	0	
	Ceiling	40	0.029	72	84	84
Master Bedroom	Ceiling	192	0.029	72	401	
	Floor	192	0.310	0	0	
	Brick Wall	128	0.051	72	468	
	B&B Wall	32	0.064	72	147	
	Glazing	40	0.560	72	1613	
	Panels	16	0.300	72	346	
	Infilt	42	0.500	72	1512	4487

Room/ Space	Structural Component	Area Crack L	U	ΔT	Heat Load (Btu/Hr)	Totals (Btu/Hr)
Hall/ Stairs	Floor	120	0.310	0	0	
	Ceiling	120	0.029	72	250	
	Brick Wall	48	0.051	72	176	426
Bedroom #2	Floor	130	0.310	0	0	
	Ceiling	130	0.029	72	271	
	Brick Wall	180	0.051	72	366	
	B&B Wall	16	0.064	72	74	
	Glazing	40	0.560	72	1623	
	Panels	16	0.300	72	346	
	Infilt	42	0.500	72	1512	4192
Bedroom #3	Same as Bedroom #2					4192
Basement	Floor	720	0.10	20	1440	
	Walls	112	0.10	38	426	1866

GRAND TOTAL: 36,378 Btu/Hr
(28% reduction)

APPENDIX B

SOLAR ENERGY SYSTEM TAB LARIZED PERFORMANCE
DATA SUMMARY

(May 1976 to April 1977)

Date	Solar Insolation (BTU/SF/Day) Cum,Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	BTU's Available	BTU's Collected	%	BTU's Available	BTU's Collected	%	
1 May	2232	19	89	111	402112	1,197,311	X	362909	360210	99.3	G.A. Sensor Malfunction
2 May	2154	17	100	118	396603	2,112,120	X	359754	286239	79.6	"
3 May	1875	20	95	112	336779	300034	89.1	303717	232014	76.4	
4 May		10									Gap in tape 0445-2400
5 May	83	12									Gap in tape 0222-1515
6 May	32.9	22	--	--	65036	0	0	59899	0	0	Tank Sensor Malfunction
7 May	1944	21	90	--	378535	2,268,872	X	347624	235066	67.6	G.A. & Tank Sensors Quit
8 May	1217	22	89	--	255053	85,827	33.7	237784	172134	72.4	Tank Sensor Out
9 May	2062	14	81	87	397395	237,996	59.9	364147	332692	91.4	R.A. Sensor Seems Off
10 May	1676	09	88	98	313945	220,361	70.2	205888	260376	91.1	"
11 May	1632	07	90	119	328957	188,837	57.4	302386	213672	70.7	"
12 May	2272	18	105	122	385591	226,012	58.6	342978	251779	73.4	"
13 May	2253	17	104	120	449920	263,751	62.5	497190	301744	77.6	"
14 May	2410	10	107	128		324,165			350545		"
15 May	1104	24	111	114	205956	50,038	24.3	187375	57799	30.8	"
16 May	1024	26	98	104	178184	74,623	41.9	159460	83406	52.3	"
17 May	2401	18	98	118	354420	293,007	82.9	303317	292985	96.6	"
18 May	492	10	100	--	94638	27,565	29.1	86693	31351	36.2	TMQ Out
19 May	1338	06	97	105	223707	14,7039	65.7	198234	150505	75.9	

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	BTU's Available	BTU's Collected	%	BTU's Available	BTU's Collected	%	
20 May	1419	06	98	195	262504	148,728	56.7	238345	157119	65.9	
21 May	474	13	100	100	91126	28,961	31.8	83474	7142	8.6	
22 May	678	17	95	99	123883	51,871	41.9	112181	74460	66.4	Clockout
23 May	N/A	16	--	--	--	--	--	--	--	--	
24 May	N/A	16	--	--	--	--	--	--	--	--	
25 May	307	13	94	94	28957	744	2.6	20536	0	0	Clock Reset
26 May	2065	13	89	108	374367	287,798	76.9	338356	296644	87.7	
27 May	1942	10	101	116	355868	230,562	64.8	322430	242237	75.1	
28 May	1528	08	101	110	273917	128,006	46.7	246909	147071	59.6	
29 May	398	08	105	107	60188	41,097	68.3	51887	43532	83.9	
30 May	1233	11	99	102	226333	69,505	30.7	205158	70007	34.1	
31 May	1962	10	98	113	373394	242,399	64.9	341199	233061	68.3	

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
1 May	2232	19	194297	43793	150504	22.5	24.00	8096
2 May	2154	17	145258	46567	98691	32.1	24.00	6052
3 May	1875	20	246958	209949	37009	85.0	24.00	10,290
4 May	N/A	10	58309	37749	20561	64.7	5.00	11,662
5 May	N/A	12	0	0	0	.0	0	0
6 May	329	22	217943	0	217943	0	24.15	9025
7 May	1944	21	200672	0	200672	0	24.03	8361
8 May	1217	22	133233	0	133233	0	15.30	8708
9 May	2062	14	70729	0	70729	0	24.00	2947
10 May	1676	09	50991	0	50991	0	24.00	2125
11 May	1632	07	75663	0	75663	0	24.00	3153
12 May	2272	18	75795	75795	0	100.0	24.02	3155
13 May	2253	17	191619	191619	0	100.0	23.20	8259
14 May	2410	10	111464	111464	0	100.0	24.00	4644
15 May	1104	24	278016	278016	0	100.0	24.00	11,584
16 May	1024	26	212706	65491	147215	30.8	24.00	8863
17 May	2401	18	127554	19816	107738	15.5	24.00	5315
18 May	492	10	129001	129001	0	100.0	11.75	10,979
19 May	1338	06	0	0	0	0	24.00	0
20 May	1419	06	0	0	0	0	24.00	0
21 May	474	13	71321	25265	46056	35.4	22.13	3223
22 May	678	17	0	0	0	0	13.50	0
23 May	--	16	--	--	--	--	0	--

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
24 May	--	16	--	--	--	--	0	--
25 May	307	13	0	0	0	0	10.15	0
26 May	2065	13	106093	0	106093	0	24.00	4421
27 May	1942	10	57857	6044	51813	10.4	24.00	2411
28 May	1528	08	110275	110275	0	100.0	24.00	4595
29 May	398	08	0	0	0	0	9.75	0
30 May	1233	11	34281	34281	0	100.0	24.00	1428
31 May	1962	10	37832	0	37832	0	24.00	3153

SOLAR TEST HOUSE DATA SUMMARY

May 1976

Days of Record Considered - 27

Total Hours Analyzed - 586

House Heating Demand - 2,938,236 Btu
(Hourly) - (5014 Btu/Hr)

Average Solar Insolation - 1497 Btu/SF

Average Number of Degree Days - 14.3

Btu Available to Solar Arrays - 12,319,485

Btu Collected by Solar Arrays and Storage Tank - 7,027,889
(57% of that available)

Btu Provided to House for Heating by Solar Energy - 1,385,125
(47% of heating demand, 50% eff)

Date	Solar Insolation (Btu/SF/Day) Cum,Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
1 Jun	1724	7	103	112	313313	251328	68.7	283349	216031	76.2	
2 Jun	1686	6	108	116	215297	137903	64.1	175580	130957	74.6	
3 Jun	1874	6	105	118	282903	200667	79.9	243723	198815	81.6	
4 Jun	1378	8	107	116	246346	120007	48.7	221939	127055	57.2	
5 Jun	973	5	108	116	191226	144688	75.7	175950	137444	78.1	Tape Jam
6 Jun	1520	0	106	118	283673	169119	59.6	258109	173035	69.0	
7 Jun	1889	0	108	125	346701	237752	68.6	314251	238692	76.0	
8 Jun	1614	0	115	118	316320	193423	61.1	290889	204641	70.4	
9 Jun	1681	0	113	125	253969	160054	63.0	218864	170040	77.7	
10 Jun	2316	0	118	132	294797	253742	86.1	240100	X	X	Water in RA Sensor
11 Jun	2573	0	124	138	414224	287274	69.4	363366	266857	73.4	
12 Jun	2417	0	130	140	380139	238664	62.8	331355	229962	69.4	
13 Jun	2331	0	134	141	346062	223882	64.7	296672	203753	68.7	
14 Jun	2503	0	129	140	386420	186794	48.3	335087	201827	60.2	
15 Jun	2916	0	122	136	470280	306692	65.2	412775	313041	75.8	
16 Jun	2490	0	120	128	402345	132338	32.9	353305	97570	27.6	Changed Pyranom RA Sensors & Roof Dry Sensor
17 Jun	1113	0	125	125	118898	9697	8.2	90020	3955	4.4	
18 Jun	N/A	0	X	X	X	X	X	X	X	X	Tape Ran Out
19 Jun	2339	0	103	125	467696	278631	59.6	431895	X	X	Water in RA Sensor
20 Jun	2390	0	122	137	392375	271516	69.2	346008	X	X	"

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
21 Jun	1680	0	133	140	268967	180378	67.1	235597	X	X	Installed New Box on RA
22 Jun	N/A	0	146	147	X	X	X	X	X	X	Tape Ran Out
23 Jun	775	0	142	141	86522	2622	3.0	66833	1096	1.6	
24 Jun	2213	10	125	135	334640	221027	66.0	288437	123395	42.8	
25 Jun	2099	4	125	136	335938	228634	68.1	2942:0	92120	31.3	
26 Jun	1599	6	132	133	223884	71065	31.7	188450	26723	14.2	
27 Jun	1743	4	130	138	274846	201324	73.2	239743	113947	47.5	
28 Jun	1841	0	134	143	301524	231766	76.9	265738	126626	47.7	
29 Jun	963	4	138	140	134594	63439	47.1	113239	39560	34.9	
30 Jun	1669	4	135	140	285737	163680	57.3	254692	80254	31.5	

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
1 Jun	1724	7	53998	53998	0	100.0	17.00	3176
2 Jun	1686	6	0	0	0	0	24.00	0
3 Jun	1874	6	43991	43991	0	100.0	24.00	1833
4 Jun	1378	8	44685	44685	0	100.0	24.00	1862
5 Jun	973	5	0	0	0	0	10.00	0
6 Jun	1520	0	29823	29823	0	100.0	24.00	1243
7 Jun	1889	0	27346	27346	0	100.0	24.00	1139
8 Jun	1614	0	7134	7134	0	100.0	20.40	350
9 Jun	1681	0	0	0	0	0	24.00	0
10 Jun	2316	0	0	0	0	0	24.00	0
11 Jun	2573	0	0	0	0	0	24.00	0
12 Jun	2417	0	4359	4359	0	100.0	24.00	182
13 Jun	2331	0	12088	12088	0	100.0	24.00	504
14 Jun	2503	0	41118	41118	0	100.0	24.00	172
15 Jun	2916	0	122957	122957	0	100.0	24.00	5123
16 Jun	2490	0	89072	89072	0	100.0	24.00	3711
17 Jun	1113	0	0	0	0	0	24.00	0
18 Jun	N/A	0	0	0	0	0	5.00	0
19 Jun	2339	0	111365	111365	0	100.0	24.00	4640
20 Jun	2390	0	20509	20509	0	100.0	24.00	855
21 Jun	1680	0	0	0	0	0	24.00	0
22 Jun	N/A	0	0	0	0	0	11.00	0

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
23 Jun	775	0	32894	32894	0	100.0	24.00	1371
24 Jun	2213	10	129893	129893	0	100.0	24.00	5412
25 Jun	2099	4	62618	62618	0	100.0	24.00	2609
26 Jun	1599	6	0	0	0	0	24.00	0
27 Jun	1743	4	0	0	0	0	24.00	0
28 Jun	1841	0	0	0	0	0	24.00	0
29 Jun	963	4	0	0	0	0	24.00	0
30 Jun	1669	4	13594	10304	6580	75.8	24.00	566

SOLAR TEST HOUSE DATA SUMMARY

June 1976

Days of Record Considered - 28

Total Hours Analyzed - 663

House Heating Demand - 847,348 Btu
(Hourly) - (1278 Btu/Hr)

Average Solar Insolation - 1868 Btu/SF

Average Number of Degree Days - 5.3

Btu Available to Solar Arrays - 14,449,254

Btu Collected by Solar Arrays and Storage Tank - 8,649,502
(60% of that available)

Btu Provided to House for Heating by Solar Energy - 844,154
(100% of heating demand, 50% eff)

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
1 Jul	1355	0	136	138	245122	91869	37.5	221443	65060	29.4	Calibrated RA & GA Sensor
2 Jul	N/A	0	125	128	--	--	--	--	--	--	Tape Out
3 Jul	N/A	3	120	125	--	--	--	--	--	--	
4 Jul	1576	0	121	130	270066	206491	76.5	240798	144014	59.8	
5 Jul	2397	0	121	135	422274	317079	75.1	379069	233427	61.6	
6 Jul	1754	0	125	137	335928	284470	84.7	307401	136332	44.3	
7 Jul	N/A	0	126	131	--	--	--	--	--	--	
8 Jul	1699	0	119	130	266145	230344	86.5	231737	113396	48.9	
9 Jul	1988	0	120	134	331936	286027	86.2	294033	162010	55.1	
10 Jul	1719	0	124	136	307477	223859	72.8	277029	135662	49.0	
11 Jul	1131	0	132	142	--	--	--	--	--	--	Tape Out
12 Jul	1900	0	131	143	336671	274372	81.5	302651	128412	42.4	
13 Jul	1243	1	135	139	172015	112789	65.6	144224	63148	43.8	
14 Jul	1859	0	134	141	280023	205789	73.5	241104	113421	47.0	
15 Jul	1204	4	130	130	199025	43417	21.8	175834	8663	4.9	
16 Jul	1931	0	120	134	--	--	--	--	--	--	
17 Jul	1849	0	130	136	331720	228419	68.9	299084	105752	35.4	
18 Jul	N/A	0	129	130	--	--	--	--	--	--	Tape Out
19 Jul	1824	0	120	126	--	--	--	--	--	--	Power Failure no Restart
20 Jul	N/A	4	118	123	--	--	--	--	--	--	

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
21 Jul	N/A	2	120	126	--	--	--	--	--	--	Installed MOV on System
22 Jul	2077	0	123	134	498311	219101	44.0	476025	146854	30.8	
23 Jul	1838	3	131	133	432972	152022	35.1	412338	57136	13.9	
24 Jul	2232	2	130	138	441372	196283	44.8	406639	81683	20.1	
25 Jul	N/A	1	126	129	--	--	--	--	--	--	Tape Out
26 Jul	N/A	2	-	-	--	--	--	--	--	--	" "
27 Jul	1590	1	112	121	291978	197841	69.8	264674	158335	59.8	
28 Jul	1353	0	115	126	258940	161681	62.4	236910	126359	53.3	
29 Jul	1780	0	121	139	347458	281607	81.0	319254	239514	75.0	
30 Jul	1287	0	135	142	255756	141370	55.3	237866	127329	53.5	
31 Jul	N/A	0	127	143	--	--	--	--	--	--	

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
1 Jul	1355	0	0	0	0	0	17.00	0
2 Jul	N/A	0	0	0	0	0	2.00	0
3 Jul	N/A	3	0	0	0	0	12.13	0
4 Jul	1576	0	0	0	0	0	24.00	0
5 Jul	2397	0	0	0	0	0	24.00	0
6 Jul	1754	0	0	0	0	0	24.00	0
7 Jul	N/A	0	0	0	0	0	13.50	0
8 Jul	1699	0	0	0	0	0	24.00	0
9 Jul	1988	0	0	0	0	0	24.00	0
10 Jul	1719	0	0	0	0	0	24.00	0
11 Jul	1131	0	0	0	0	0	16.50	0
12 Jul	1900	0	0	0	0	0	24.00	0
13 Jul	1243	1	0	0	0	0	24.00	0
14 Jul	1859	0	0	0	0	0	22.00	0
15 Jul	1204	4	0	0	0	0	24.00	0
16 Jul	1931	0	0	0	0	0	24.00	0
17 Jul	1849	0	1486	1486	0	100.0	24.00	61.9
18 Jul	N/A	0	0	0	0	0	19.50	0
19 Jul	1824	0	0	0	0	0	16.75	0
20 Jul	N/A	4	0	0	0	0	11.00	0
21 Jul	N/A	2	--	--	--	--	--	0
22 Jul	2077	0	0	0	0	0	17.00	0

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
23 Jul	1838	3	0	0	0	0	24.00	0
24 Jul	2232	2	0	0	0	0	24.00	0
25 Jul	N/A	1	0	0	0	0	6.75	0
26 Jul	N/A	2	--	--	--	--	--	0
27 Jul	1590	1	0	0	0	0	17.00	0
28 Jul	1353	0	0	0	0	0	24.00	0
29 Jul	1780	0	0	0	0	0	24.00	0
30 Jul	1287	0	0	0	0	0	20.75	0
31 Jul	N/A	0	0	0	0	0	10.75	0

SOLAR TEST HOUSE DATA SUMMARY

July 1976

Days of Record Considered - 22

Total Hours Analyzed - 563

House Heating Demand - 1486 Btu
(Hourly) - (2.64 Btu/Hr)

Average Solar Insolation - 1708 Btu/SF

Average Number of Degree Days - 0.75

Btu Available to Solar Arrays - 11,493,302

Btu Collected by Solar Arrays and Storage Tank - 6,201,337
(54% of that available)

Btu Provided to House for Heating by Solar Energy - 1486
(100% of heating demand)

Date	Solar Insolation (Btu/SF/Day) Cum,Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
1 Aug	--	2	130	132	--	--	--	--	--	--	Tape Out
2 Aug	131	9	126	119	18464	0	0	15581	0	0	
3 Aug	1311	3	111	123	279650	205346	73.4	261600	141405	54.1	
4 Aug	1565	0	113	119	303145	247430	81.6	--	--	--	RA Pump Switch Failed
5 Aug	N/A	1	-	-	--	--	--	--	--	--	
6 Aug	1837	4	114	125	328998	263687	80.1	--	--	--	Switch Fixed
7 Aug	1104	0	116	-	244628	203444	83.2	227192	130336	57.4	
8 Aug	1312	0	116	127	275263	201983	73.4	256675	139881	54.5	
9 Aug	728	0	115	118	147906	102226	69.1	137031	53470	39.0	
10 Aug	1492	0	112	130	341300	304331	89.2	323371	218428	67.5	
11 Aug	1265	0	117	126	249871	137070	54.9	230162	109113	47.4	
12 Aug	1685	0	116	132	323997	258243	79.7	296717	206569	69.6	
13 Aug	556	0	122	-	123729	44364	35.9	116288	27987	24.1	
14 Aug	1564	1	116	134	309314	279388	90.3	284996	299474	80.5	
15 Aug	N/A	1	-	-	--	--	--	--	--	--	
16 Aug	2489	0	132	144	517645	267861	51.7	481830	247347	51.3	
17 Aug	1580	0	133	146	314291	262688	83.6	289945	149175	51.4	
18 Aug	1341	0	136	143	288304	131791	45.9	270084	84848	31.4	
19 Aug	909	1	128	133	207739	97075	46.7	196816	47915	24.3	
20 Aug	1634	0	120	139	383870	276788	72.1	365403	188940	51.7	

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
21 Aug	1838	0	134	147	405882	280254	69.0	382161	191262	50.0	
22 Aug	1598	0	142	151	365523	242257	66.3	346334	202326	58.4	
23 Aug	575	0	136	136	130699	14634	11.2	123712	5906	4.8	
24 Aug	1303	3	126	135	300468	186510	62.1	285115	92131	32.3	
25 Aug	1683	1	125	139	388676	299914	77.2	368888	246141	66.7	
26 Aug	1712	0	127	140	390665	268955	68.8	--	--	--	RA Valve Failure
27 Aug	1834	6	138	-	394437	277201	70.3	--	--	--	Tank Sensor Failure
28 Aug	1777	7	142	150	411660	286285	69.5	--	--	--	RA Valve Tank Sensor
29 Aug	1321	7	135	143	292968	198863	67.9	--	--	--	"
30 Aug	1148	5	128	137	280347	126804	45.2	268596	163456	60.9	"
31 Aug	1435	4	124	137	365901	209706	57.3	352976	206487	58.5	"

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
1 Aug	N/A	2						
2 Aug	131	9	0	0	0	0	15.00	0
3 Aug	1311	3	46072	46072	0	100.0	23.30	1977.3
4 Aug	1565	0	0	0	0	0	24.00	0
5 Aug	N/A	1	0	0	0	0	15.75	0
6 Aug	1837	4	0	0	0	0	24.00	0
7 Aug	1104	0	0	0	0	0	20.08	0
8 Aug	1312	0	0	0	0	0	24.00	0
9 Aug	728	0	0	0	0	0	24.00	0
10 Aug	1492	0	0	0	0	0	24.00	0
11 Aug	1265	0	0	0	0	0	24.00	0
12 Aug	1685	0	0	0	0	0	24.00	0
13 Aug	556	0	0	0	0	0	13.75	0
14 Aug	1564	1	0	0	0	0	24.00	0
15 Aug	N/A	1	0	0	0	0	14.75	0
16 Aug	2489	0	1486	1486	0	100.0	22.50	66.0
17 Aug	1580	0	0	0	0	0	24.00	0
18 Aug	1341	0	0	0	0	0	24.00	0
19 Aug	909	1	0	0	0	0	23.25	0
20 Aug	1634	0	0	0	0	0	24.00	0
21 Aug	1838	0	0	0	0	0	24.00	0
22 Aug	1598	0	0	0	0	0	24.00	0

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
23 Aug	575	0	0	0	0	0	24.00	0
24 Aug	1303	3	0	0	0	0	23.25	0
25 Aug	1683	1	0	0	0	0	24.00	0
26 Aug	1834	0	0	0	0	0	24.00	0
27 Aug	1834	6	0	0	0	0	24.00	0
28 Aug	1777	7	0	0	0	0	24.00	0
29 Aug	1321	7	0	0	0	0	22.00	0
30 Aug	1148	5	0	0	0	0	16.50	0
31 Aug	1435	4	0	0	0	0	24.00	0

SOLAR TEST HOUSE DATA SUMMARY

August 1976

Days of Record Considered - 28

Total Hours Analyzed - 642

House Heating Demand - 47,558 Btu
(Hourly) - (74.06 Btu/Hr)

Average Solar Insolation - 1387 Btu/SF

Average Number of Degree Days - 1.77

Btu Available to Solar Arrays - 14,266,813

Btu Collected by Solar Arrays and Storage Tank - 8,757,695
(61.4% of that available)

Btu Provided to House for Heating by Solar Energy - 47,558
(100% of heating demand)

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
1 Sep	1653	8	124	--	395857	274682	69.6	378028	184336	48.8	Tank Sensor Fail
2 Sep	1766	7	--	--	401370	265546	66.2	379881	146421	38.5	" " "
3 Sep	1752	2	--	--	408088	--	--	387881	--	--	Fixed
4 Sep	1404	1	129	130	346918	256927	74.1	333017	148413	44.6	
5 Sep	1618	0	120	132	409134	313940	76.7	394188	184683	46.9	
6 Sep	1258	2	126	130	313251	217551	69.4	301098	123204	40.9	
7 Sep	1135	4	124	135	290678	215332	74.1	280590	126549	45.1	
8 Sep	250	18	124	119	65185	0	0	63107	0	0	
9 Sep	599	16	108	107	153486	30783	20.1	148180	374	0.3	
10 Sep	1203	8	100	114	310316	240550	77.5	299898	149792	49.9	
11 Sep	1238	1	107	127	320381	303154	94.6	309575	201977	65.2	
12 Sep	1310	0	123	134	346836	261381	75.4	336518	154664	46.0	
13 Sep	1178	6	130	137	314571	[illegible]498	55.5	305543	96667	31.6	
14 Sep	831	7	132	134	220722	140516	63.7	214239	89235	41.7	
15 Sep	858	6	118	124	220031	115937	52.9	212451	68957	32.5	
16 Sep	N/A	9			--	--	--	--	--	--	Power Failure
17 Sep	1101	2	105	120	306835	256150	83.5	299921	170436	56.8	
18 Sep	1166	3	107	120	327363	250335	76.5	320305	146047	45.6	
19 Sep	N/A	11	112		--	--	--	--	--	--	Data Conversion
20 Sep											Plumbing Mod.
											Shut Down

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
1 Sep	1653	8	0	0	0	0	23.75	0
2 Sep	1766	7	0	0	0	0	24.00	0
3 Sep	1752	2	0	0	0	0	24.00	0
4 Sep	1404	1	0	0	0	0	24.00	0
5 Sep	1618	0	0	0	0	0	24.00	0
6 Sep	1258	2	0	0	0	0	23.15	0
7 Sep	1135	4	0	0	0	0	22.50	0
8 Sep	250	18	0	0	0	0	24.00	0
9 Sep	599	16	148619	148619	0	100.0	24.00	6192.5
10 Sep	1203	8	120602	84415	36187	70.0	23.50	5132
11 Sep	1238	1	38839	38839	0	100.0	24.00	1618.3
12 Sep	1310	0	0	0	0	0	24.00	0
13 Sep	1178	6	0	0	0	0	24.00	0
14 Sep	831	7	1486	1486	0	100.0	24.00	0
15 Sep	858	6	66185	66185	0	100.0	24.00	2757.7
16 Sep	N/A	9	75696	75696	0	100.0	12.00	6308.0
17 Sep	1101	2	0	0	0	0	24.00	0
18 Sep	1166	3	72526	72526	0	100.0	18.50	3920.3
19 Sep	N/A	11	0	0	0	0	16.25	0

SOLAR TEST HOUSE DATA SUMMARY

September 1976

Days of Record Considered - 16

Total Hours Analyzed - 427

House Heating Demand - 794,271
(Hourly) - (1860 Btu/Hr)

Average Solar Insolation - 1129 Btu/SF

Average Number of Degree Days - 5.84

Btu Available to Solar Arrays - 9,319,601

Btu Collected by Solar Arrays and Storage Tank - 5,310,037
(57% of that available)

Btu Provided to House for Heating by Solar Energy - 757,766
(95% heating demand, 50% eff)

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
1 Oct	907	23	102	106	313,184	109,806	35.1	317,291	115,786	36.5	
2 Oct	1150	23	96	113	422,995	234,429	55.4	425,830	261,925	61.5	
3 Oct	713	10	97	105	167,086	105,595	63.2	177,431	90,379	50.9	RA Valve out
4 Oct	670	7	94	102	204,919	127,207	62.1	210,298	23,573	11.2	RA Valve out
5 Oct		9									
6 Oct	527	28	96	96	168,888	4,356	2.6	172,438	7,255	4.2	
7 Oct	1414	30	91	108	431,196	324,468	75.2	442,704	210,305	47.5	
8 Oct	1378	21	99	124	457,254	341,448	74.7	465,101	320,506	68.9	
9 Oct	404*	14	100	127	131,262	78,915	60.1	133,808	80,885	60.4	Pyranometer Out
10 Oct	1112*	10	111	136	363,032	321,651	88.6	369,922	282,950	76.5	"
11 Oct	N/A	4	114	134	--	287,060	--	--	244,501	--	"
12 Oct	N/A	16	108	127	--	297,755	--	--	282,066	--	"
13 Oct	N/A	17	120	125	--	110,885	--	--	74,705	--	"
14 Oct	N/A	12	111	92	--	260,898	--	--	216,328	--	"
15 Oct	N/A	26	88	134	--	260,532	--	--	230,284	--	"
16 Oct	1326	28	126	135	291,774	240,231	82.3	312,712	152,512	48.8	Pyranometer Adjustment
17 Oct	1342	21	120	124	339,501	198,726	58.5	356,694	124,327	34.9	
18 Oct	274	34	109	108	105,523	636	0.6	105,770	431	0.4	
19 Oct	950	34	97	-	382,694	337,283	88.1	382,046	274,808	71.9	
20 Oct	1002	30	94	-	384,993	339,938	88.3	385,992	267,795	69.4	
21 Oct	1102	24	100	-	412,595	310,815	75.3	414,673	258,819	62.4	
22 Oct	1914	23	104	118	750,9.9	229,880	30.6	751,414	179,453	23.9	
23 Oct	810*	19	103	122	300,063	283,375	94.4	301,853	226,863	75.2	Pyranometer Out

Date	Solar Insolation (Btu/SF/Day) Cum,Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
24 Oct	1589	27	108	115	615,560	195,020	31.7	616,677	167,384	27.1	
25 Oct	1344	23	97	104	555,464	170,973	30.8	553,281	133,346	24.1	
26 Oct	405	30	-	-	206,926	--	-	202,697	--	-	
27 Oct	363	35	-	-	142,043	--	0	142,160	0	0	
28 Oct	1744	38	89	104	810,278	440,481	54.4	799,377	4,280	0.5	
29 Oct	2093	33	99	-	1,001,670	371,820	37.1	985,956	148,253	15.0	
30 Oct	1786	25	98	114	466,206	282,752	60.6	487,797	238,080	60.6	
31 Oct	1401	25	99	119	560,397	284,024	50.7	559,780	226,549	40.5	

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
1 Oct	907	23	0	0	0	0	24.00	0
2 Oct	1150	23	29608	0	29608	0	24.00	1234
3 Oct	713	10	207410	124,345	83065	60.0	22.50	9218
4 Oct	670	7	135273	16843	118430	12.5	17.65	7664
5 Oct		9						
6 Oct	527	28	259065	0	259065	0	24.00	10794
7 Oct	1414	30	102330	97395	4935	95.2	24.00	4264
8 Oct	1378	21	218078	35966	92112	28.1	24.00	5337
9 Oct	404*	14	202022	202022	0	100.0	24.00	8418
10 Oct	1112*	10	161301	161301	0	100.0	24.00	6721
11 Oct	N/A	4	77183	77183	0	100.0	24.00	3216
12 Oct	N/A	16	64005	64005	0	100.0	24.00	2667
13 Oct	N/A	17	166651	166561	0	100.0	24.00	6943
14 Oct	N/A	12	106739	97692	9047	91.5	24.00	4447
15 Oct	N/A	26	80340	9611	70729	12.0	18.75	4285
16 Oct	1326	28	26950	26950	0	100.0	24.00	1123
17 Oct	1342	21	290005	290005	0	100.0	24.00	12083
18 Oct	247	34	252260	211138	41122	83.7	21.38	11799
19 Oct	950	34	283924	131775	152149	46.4	23.00	12345
20 Oct	1002	30	311577	279502	32075	89.7	22.50	13847
21 Oct	1102	24	237407	198752	38655	83.7	22.75	10435
22 Oct	1914	23	196683	190926	5757	97.1	24.00	8195
23 Oct	810*	19	140445	136333	4112	97.1	24.00	5852
24 Oct	1589	27	313487	313487	0	100.0	24.00	13061

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
25 Oct	1344	23	290642	141782	14860	48.8	24.00	12110
26 Oct	405	30	313345	0	313345	0	24.00	13056
27 Oct	363	35	338840	0	338840	0	24.00	14118
28 Oct	1744	38	248374	0	248374	0	24.00	10349
29 Oct	2093	33	247168	78570	168598	31.8	24.00	10299
30 Oct	1786	25	236567	177352	59215	75.0	24.00	9857
31 Oct	1401	25	292488	226693	65795	77.5	24.00	12187

SOLAR TEST HOUSE DATA SUMMARY

October 1976

Days of Record Considered - 30

Total Hours Analyzed - 700

House Heating Demand - 5,739,980
(Hourly) - (8200 Btu/Hr)

Average Solar Insolation - 1154 Btu/SF

Average Number of Degree Days - 22.5

Btu Available to Solar Arrays - 18,460,164

Btu Collected by Solar Arrays and Storage Tank - 7,855,654
(43% of that available)

Btu Provided to House for Heating by Solar Energy - 3,456,279
(60% heating demand, 50% eff) (18.7% of that available)

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
1 Nov	1150	18	102	124	500,363	325,384	65.0	496,219	259,528	52.3	
2 Nov	1012	24	109	123	451,020	304,449	67.5	446,398	245,463	55.0	
3 Nov	903	26	100	118	405,416	351,099	86.6	401,050	257,970	64.3	
4 Nov	624	25	108	110	286,498	110,943	38.7	282,929	97,403	34.4	
5 Nov	1414	18	102	124	620,217	417,257	67.3	514,693	130,353	21.2	
6 Nov	965	18	111	119	481,186	298,596	62.1	472,185	191,464	40.5	
7 Nov	878	28	99	116	424,145	398,000	93.8	417,775	211,888	50.7	GA Leak
8 Nov	--	12			--	--	--	--	--	--	
9 Nov	1095	21	100	118	481,673	476,040	98.0	477,263	247,444	51.8	GA Leak
10 Nov	563	24	98	100	262,491	126,544	48.2	258,895	55,992	21.6	GA Leak
11 Nov	118	36			52,627	0	0	52,085	0	0	Snow & Clouds
12 Nov	124	45			54,177	0	0	53,686	0	0	Snow & Clouds
13 Nov	136	41			63,918	0	0	62,994	0	0	Snow & Clouds
14 Nov	703	28	97	112	--	--	--	--	--	--	System Testing
15 Nov	965	35	94	112	476,054	*	*	467,546	266,618	57.0	GA Leak
16 Nov	876	33	97	110	435,614	418,828	96.2	427,557	206,282	48.4	GA Leak
17 Nov	621	21	96	106	367,023	*	*	362,715	219,045	60.4	GA Leak
18 Nov											
19 Nov	703	22	97	111	330,627	*	*	325,863	205,996	63.2	GA Leak
20 Nov	845	31	91	106	431,165	*	*	422,382	230,789	54.6	GA Leak
21 Nov	754	39	89	102	388,943	*	*	380,727	241,521	63.4	GA Leak
22 Nov	315	30	88	89	144,496	27,589	19.0	142,669	23,640	16.6	Fixed
23 Nov	839	33	85	106	432,239	292,169	67.6	423,161	257,155	60.8	
24 Nov	686	17	89	111	344,757	321,322	93.2	346,625	271,908	78.4	

Date	Solar Insolation (Btu/SF/Day) Cum,Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
25 Nov	641	22	91	102	333,935	174,786	52.4	326,670	169,592	52.0	
26 Nov	231	44			115,969	0	0	113,739	0	0	
27 Nov											
28 Nov	500	61	86	96	267,524	227,016	84.8	261,231	169,217	64.7	
29 Nov	473	39	89	97	283,323	276,955	49.3	276,955	110,933	40.0	
30 Nov	466	33	88	93	248,164	70,506	28.4	242,375	61,978	25.8	

Date	Solar Insolation (Btu/SF/Day) Cum,Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
1 Nov	1150	18	200360	180,621	19739	90.1	24.00	8348
2 Nov	1012	24	206877	206,877	0	100.0	24.00	8620
3 Nov	903	26	195762	73,220	122542	37.4	23.50	8330
4 Nov	624	25	346876	346,876	0	100.0	24.00	14453
5 Nov	1414	18	193652	173,091	20561	89.4	24.00	8069
6 Nov	965	18	211145	221,145	0	100.0	24.00	8798
7 Nov	878	28	341403	284,655	56748	83.3	24.00	14225
8 Nov	--	12	849615	138,215	711400	16.3	24.00	35401
9 Nov	1095	21	238187	120,579	117608	50.6	24.00	9924
10 Nov	563	24	296971	178,541	118430	60.1	21.00	14141
11 Nov	118	36	276336	0	276336	0	19.25	14355
12 Nov	124	45	414504	0	414504	0	24.00	17271
13 Nov	136	41	305943	0	305943	0	15.67	19524
14 Nov	703	28	61174	29,922	31252	48.9	14.90	4106
15 Nov	965	35	218848	197,465	21383	90.2	24.00	9119
16 Nov	876	33	413997	248,689	165308	60.0	24.00	17250
17 Nov	621	21	299491	133,361	166130	44.5	24.00	12479
18 Nov		18						
19 Nov	703	22	375839	358,568	17271	95.4	22.50	16704
20 Nov	845	31	444988	408,801	36187	91.9	24.00	18541
21 Nov	754	39	472839	313,288	159551	66.3	24.00	19702
22 Nov	315	30	376998	7,728	369270	2.0	24.00	15708
23 Nov	839	33	367236	144,358	222878	39.3	24.00	15302
24 Nov	686	17	198146	110,969	87177	56.0	18.02	10996
25 Nov	641	22	270609	226,198	44411	83.4	24.00	11275

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
26 Nov	231	17	458494	52,215	406279	11.4	23.00	19935
27 Nov		64						
28 Nov	500	61	434761	183,098	251663	42.1	24.00	18115
29 Nov	473	39	270579	0	270579	0	16.00	16911
30 Nov	466	33	404635	0	404635	0	24.00	16860

SOLAR TEST HOUSE DATA SUMMARY

November 1976

Days of Record Considered - 29

Total Hours Analyzed - 585

House Heating Demand - 11,364,008 Btu
(Hourly) - (19,426 Btu/Hr)

Average Solar Insolation - 727 Btu/SF

Average Number of Degree Days - 30.2

Btu Available to Solar Arrays - 15,968,818

Btu Collected by Solar Arrays and Storage Tank - 9,201,476
(57.6% of that available)

Btu Provided to House for Heating by Solar Energy - 4,449,449
(44% of heating demand, 50% eff) (27.9% of that available)

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
1 Dec	116*	41	90	95	40145	0	0	38588	0	0	Partial Data
2 Dec	315*	25	89	107	180090	114670	63.6	175062	84071	48.1	Partial Data
3 Dec	--	33	100	95	--	--		--	--		
4 Dec	698	34	92	106	343912	238310	69.3	337850	191445	56.6	
5 Dec	449	44	98	104	232896	120555	51.8	227926	111276	48.8	
6 Dec	579	46	97	107	310950	209824	67.5	303559	159023	52.4	
7 Dec	575	34	98	102	216801	76318	35.2	217764	81014	37.2	
8 Dec	659	28	92	101	378894	111202	29.3	368254	86680	23.5	
9 Dec	371	24	89	95	181250	119443	65.9	178099	89637	50.3	
10 Dec	654	42	8[illegible]	95	336807	128336	38.1	329742	90779	27.5	
11 Dec		35									
12 Dec		37									
13 Dec		29									
14 Dec	694	31	97	106	408743	191963	46.9	396652	151438	38.2	
15 Dec	380*	31	90	100	232447	158274	68.1	224994	112092	50.0	Partial Data
16 Dec	416*	25	88	102	298572	145516	48.7	286502	93063	32.5	Partial Data
17 Dec	503*	27	88	105	294554	221629	75.2	285912	170079	59.5	Partial Data
18 Dec		26									
19 Dec	556	40	90	98	312147	268713	86.1	303863	209461	69.0	
20 Dec		42									
21 Dec	274*	36	88	98	297519	135746	45.6	290159	87924	30.3	Partial Data
22 Dec		39									

Date	Solar Insolation (Btu/SF/Day) Cum,Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
23 Dec	924	37	86	94	529850	206479	39.0	515002	143438	27.9	
24 Dec		35									
25 Dec	852	37	86	99	471760	360746	76.5	459591	224038	48.7	
26 Dec		18									
27 Dec	1182	30	90	106	677589	328341	48.5	658628	259076	39.3	
28 Dec	880	36	90	101	492785	346793		479696	213426		
29 Dec	814	23	89	98	470041	254543	54.2	456681	182102	39.9	
30 Dec	195	42	90	88	97730	0	0	85975	0	0	
31 Dec	975	49	85	94	517369	320233	61.8	505469	161040	31.8	

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
1 Dec	116*	41	203962	0	203962	0	9.00	22662
2 Dec	315*	25	315622	136333	179289	43.2	18.87	16726
3 Dec	--	33	95402	0	95402	0	5.20	18346
4 Dec	698	34	411902	66482	345420	16.1	24.00	17163
5 Dec	449	44	388402	29823	358579	7.7	24.00	16183
6 Dec	579	46	568859	160112	408747	28.1	24.00	23702
7 Dec	575	34	363513	0	363513	0	24.00	15146
8 Dec	659	28	349532	0	349532	0	17.00	20561
9 Dec	371	24	74019	0	74019	0	16.00	4626
10 Dec	654	42	270579	0	270579	0	16.00	16911
11 Dec		35						
12 Dec		37						
13 Dec		29						
14 Dec	694	31	395833	264244	131589	66.8	24.00	16493
15 Dec	380*	31	439385	347273	92112	79.0	21.14	20785
16 Dec	416*	25	382838	188745	194093	49.3	21.05	18187
17 Dec	503*	27	377745	190231	187514	50.4	21.17	17843
18 Dec		26						
19 Dec	556	40	491082	309325	181757	63.0	24.00	20462
20 Dec		42						
21 Dec	274*	36	375450	150105	225345	40.0	19.57	19185
22 Dec		39						
23 Dec	924	37	374572	41514	333058	11.1	24.00	15607

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
24 Dec		35						
25 Dec	852	37	449445	202716	246729	45.1	24.00	18727
26 Dec		18						
27 Dec	1182	30	353322	278528	65794	81.4	24.00	14722
28 Dec	880	36	358348	260479	97869	72.7	24.00	14931
29 Dec	814	23	313274	141386	171888	45.1	24.00	13053
30 Dec	195	42	356111	0	356111	0	24.00	14838
31 Dec	975	49	407662	58952	348710	14.5	24.00	16986

SOLAR TEST HOUSE DATA SUMMARY

December 1976

Days of Record Considered - 22

Total Hours Analyzed - 477

House Heating Demand - 8,088,881 Btu
(Hourly) - (16,958 Btu/Hr)

Average Solar Insolation - 691 Btu/SF

Average Number of Degree Days - 34.0

Btu Available to Solar Arrays - 14,394,822

Btu Collected by Solar Arrays and Storage Tank - 6,958,739
(48.3% of that available)

Btu Provided to House for Heating by Solar Energy - 2,781,251
(34.4% of heating demand, 50% eff) (19.3% of that available)

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
1 Jan	379	53	89	86	193162	0	0	189242	0	0	
2 Jan	1010	36	83	95	559247	295576	53	544807	175203	32	
15 Jan	605	38	91	100	313698	395081	126	306969	199361	65	
16 Jan	621	43	88	94	251961	368088	146	251366	172515	69	
17 Jan	678	35	89	92	328729	483992	147	323241	188001	58	
18 Jan	446	28	89	90	233918	253395	108	226731	72060	32	
19 Jan	571	32	88	98	251762	272798	108	249410	119699	48	
20 Jan	477	30	89	102	218486	1778295	814	215770	237903	110	
21 Jan	578	36	91	93	270836	174529	64	267011	179841	67	
22 Jan	785	28	91	91	399887	24606	6	391806	54515	14	
23 Jan	420	35	90	87	200755	10538	5	197615	15642	8	
24 Jan	169	42	89	93	91081	51168	56	88906	48806	55	
25 Jan	228	41	91	96	121148	17590	15	118340	16657	14	
26 Jan	1073	28	92	102	533026	285464	54	523203	355366	68	
27 Jan	0	33	93	103	0	0	0	0	0	0	
28 Jan	315	40	92	91	137577	0	0	136398	0	0	
29 Jan	1110	40	86	100	515984	304145	59	509026	487078	96	
30 Jan	1080	41	86	98	499315	252393	51	492793	204644	42	
31 Jan	435	28	91	102	197455	121177	61	195156	94231	48	

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
1 Jan	379	53	580634	0	580634	0	24	24,193
2 Jan	1010	36	497596	48549	449046	9.8	24	20,733
15 Jan	605	38	505634	244924	260709	48.4	22	22,983
16 Jan	621	43	571586	134054	437532	23.5	24	23,816
17 Jan	678	35	377321	109582	267739	29.0	21	17,968
18 Jan	446	28	413436	88577	324859	21.4	21	19,687
19 Jan	571	32	391114	50629	340485	12.9	24	16,296
20 Jan	477	30	446882	161499	285383	36.1	22	20,313
21 Jan	578	36	439495	98187	341308	22.3	22	19,977
22 Jan	785	28	336164	5548	330616	1.7	21	16,008
23 Jan	420	35	273869	0	273869	0	15	18,258
24 Jan	169	42	160435	83127	77308	51.8	7	22,919
25 Jan	228	41	334316	62915	271401	18.8	15	22,288
26 Jan	1073	28	450223	258597	191626	57.4	23	19,575
27 Jan	0	33	124766	63906	60860	51.2	7	17,824
28 Jan	315	40	316977	53800	263177	17.0	19	16,683
29 Jan	1110	40	512720	223225	289495	43.5	24	21,363
30 Jan	1080	41	484321	237592	246729	49.1	24	20,180
31 Jan	435	28	227399	79362	148037	34.9	15	15,160

SOLAR TEST HOUSE DATA SUMMARY

January 1977

Days of Record Considered - 19

Total Hours Analyzed - 375

House Heating Demand - 8,286,410 Btu
(Hourly) - (22,097 Btu/Hr)

Average Solar Insolation - 634 Btu/SF

Average Number of Degree Days - 38.4

Btu Available to Solar Arrays - 10,113,583

Btu Collected by Solar Arrays and Storage Tank - 4,807,498
(47.4% of that available)

Btu Provided to House for Heating by Solar Energy - 2,004,075
(27.0% of heating demand, 50% eff) (19.8% of that available)

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
1 Feb	904	39	90	99	35255	184722	52	352983	176512	50	
2 Feb	777	42	91	95	464447	110145	24	450284	115953	26	
3 Feb	1070	37	89	106	474646	299317	63	466984	261404	56	
4 Feb	887	36	92	94	403661	162009	40	398870	148920	37	
5 Feb	733	33	90	93	321613	116967	36	318744	116898	37	
6 Feb	1105	35	86	101	468883	289294	62	465974	258386	55	
7 Feb	1100	36	91	106	461654	282736	61	459238	264552	58	
8 Feb	1213	30	90	102	544344	321314	59	538497	343645	64	
9 Feb	1238	28	89	108	525116	346887	66	521867	326632	63	
10 Feb	1259	29	88	111	537868	356768	66	534247	303709	57	
11 Feb	985	30	90	100	405979	155961	38	404482	207352	51	
12 Feb	1133	27	84	98	472907	237835	50	470646	244658	52	
13 Feb	925	27	82	96	627538	171546	27	603933	185202	31	
14 Feb	645	42	83	83	281668	5914	2	279270	2426	1	
15 Feb	1151	40	80	93	481245	229304	48	478881	202307	42	
16 Feb	1281	26	89	104	522376	257196	49	520907	280378	54	
17 Feb	1147	21	85	99	463684	191300	41	462306	205473	44	
18 Feb	1074	27	91	104	415572	183576	44	416386	191661	46	
19 Feb	941	32	92	110	381280	172341	45	380436	180819	48	
20 Feb	469	27	91	112	186067	119296	64	186676	110603	59	
21 Feb	--	14	--	--	--	--	--	--	--	--	
22 Feb	--	26	--	--	--	--	--	--	--	--	
23 Feb	0	33	27	27	0	0	0	0	0	0	

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
24 Feb	--	34	--	--	--	--	--	--	--	--	
25 Feb	70	46	89	89	24817	0	0	25064	0	0	
26 Feb	503	46	88	92	180220	195536	108	181901	23295	13	
27 Feb	1102	44	88	93	386772	145678	38	391160	59756	15	
28 Feb	1523	34	89	106	536873	320979	60	542733	296659	55	

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
1 Feb	904	39	447704	295355	152349	66.0	24	18,654
2 Feb	777	42	417954	99674	318280	23.8	24	17,415
3 Feb	1070	37	329114	187656	141458	57.0	19	17,322
4 Feb	887	36	430535	128704	301831	29.9	24	17,939
5 Feb	733	33	398002	45180	352822	11,4	22	18,091
6 Feb	1105	35	335551	109383	226168	32.6	21	15,979
7 Feb	1100	36	465489	301003	164486	64.7	22	21,159
8 Feb	1213	30	569037	386508	182529	67.9	24	23,710
9 Feb	1238	28	342790	151987	190803	44.3	19	18,042
10 Feb	1259	29	312521	259885	25636	83.2	21	14,882
11 Feb	985	30	304963	261074	43888	85.6	19	16,051
12 Feb	1133	27	224027	125335	98692	55.9	19	11,791
13 Feb	925	27	294756	226495	68262	76.8	24	12,282
14 Feb	645	42	363592	3369	360223	1.0	24	15,150
15 Feb	1151	40	305802	31111	274691	10.2	22	13,900
16 Feb	1281	26	186041	69256	116785	37.2	24	7,752
17 Feb	1147	21	209453	209453	0	100.0	24	8,727
18 Feb	1074	27	133320	30518	102804	22.9	17	7,842
19 Feb	941	32	192928	72031	120897	37.3	21	9,187
20 Feb	469	27	148125	131676	16449	88.9	15	9,874
21 Feb	--	14	--	--	--	--	--	--
22 Feb	--	26	--	--	--	--	--	--

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
23 Feb	0	33	53458	0	53458	0	5	10,692
24 Feb	--	34	--	--	--	--	--	--
25 Feb	70	46	56748	0	56748	0	23	13,090
26 Feb	503	46	301059	0	301059	0	23	13,090
27 Feb	1102	44	268973	9908	259065	3.7	23	11,694
28 Feb	1523	34	246510	120678	125832	49.0	22	11,205

<u>SOLAR TEST HOUSE DATA SUMMARY</u>

February 1977

Days of Record Considered - 25

Total Hours Analyzed - 505

House Heating Demand - 7,337,946 Btu
(Hourly) - (14,530 Btu/Hr)

Average Solar Insolation - 939 Btu/SF

Average Number of Degree Days - 25.8

Btu Available to Solar Arrays - 19,776,619

Btu Collected by Solar Arrays and Storage Tank - 9,363,758
(47.3% of that available)

Btu Provided to House for Heating by Solar Energy - 3,256,238
(44.0% of heating demand, 50% eff) (16.5% of that available)

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
1 Mar	1056	38	91	93	367559	55265	15	372054	99086	27	
2 Mar	896	44	84	90	305890	68932	23	310237	98679	32	
3 Mar	1234	43	88	98	407720	159452	39	414935	189824	46	
4 Mar	1505	46	90	105	490411	215605	44	499815	258465	52	
5 Mar	916	44	92	100	302198	118402	39	307582	132244	43	
6 Mar	1556	35	90	108	501485	299144	60	511709	312378	61	
7 Mar	1158	18	88	99	374900	100620	27	382343	179639	47	
8 Mar	1599	22	91	113	503064	288582	57	514683	310549	60	
9 Mar	1553	24	98	115	483157	247483	51	494918	281104	57	
10 Mar	591	35	99	92	187426	0	0	191566	0	0	
11 Mar	717	42	86	85	219203	0	0	224985	0	0	
12 Mar	1705	36	93	94	511989	359380	70	526563	-2548	0	
13 Mar	1635	27	87	104	486305	322551	66	500700	185657	37	
14 Mar	1527	29	85	104	444516	260332	59	458828	235339	51	
15 Mar	1667	37	86	103	482075	285518	59	497975	282429	57	
16 Mar	1341	28	83	98	384671	226505	59	397769	231108	58	
17 Mar	733	30	83	99	210205	75834	36	217376	94232	43	
18 Mar	1549	31	90	106	432764	235844	54	448935	262810	59	
19 Mar	1714	34	87	106	473203	282902	60	491593	300102	61	
20 Mar	1145	36	87	97	312409	110737	35	325034	122476	38	
21 Mar	1802	38	89	107	485505	287239	59	505922	287706	57	
22 Mar	990	27	86	109	263380	106534	40	274888	106447	39	

Date	Solar Insolation (Btu/SF/Day) Cum,Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
23 Mar	672	23	90	105	176084	64244	36	184131	47649	26	
24 Mar	240	18	92	112	60791	2301	4	63853	1208	2	
25 Mar	1192	19	99	107	303364	129351	43	318482	117876	37	
26 Mar	1555	22	92	109	394679	233518	59	414496	232852	56	
27 Mar	1751	22	92	112	438805	266117	61	461604	246405	53	
28 Mar	1793	33	99	110	443847	199067	45	467705	211019	45	
29 Mar	1449	41	90	99	352953	160978	46	372732	153518	41	
30 Mar	0	35	103	103	0	0	0	0	0	0	
31 Mar	1557	30	88	100	371402	191749	52	393372	206522	53	

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
1 Mar	1056	38	301025	163679	137346	54.4	21	14335
2 Mar	896	44	280448	0	280448	0	24	11685
3 Mar	1234	43	262061	76192	185869	29.1	22	11912
4 Mar	1505	46	278286	136828	141458	49.2	21	13252
5 Mar	916	44	171229	50332	120897	29.4	15	11415
6 Mar	1556	35	198755	64699	134056	32.6	19	10461
7 Mar	1158	18	90658	90657	0	100.0	16	5545
8 Mar	1599	22	90454	30417	60037	33.6	24	3769
9 Mar	1553	24	163976	163976	0	100.0	24	6771
10 Mar	591	35	290127	245716	44411	84.7	22	13186
11 Mar	717	42	282915	0	282915	0	24	11788
12 Mar	1705	36	201669	52809	148860	26.2	24	8403
13 Mar	1635	27	136919	41217	95402	30.3	21	6520
14 Mar	1527	29	284754	284754	0	100.0	22	12856
15 Mar	1667	37	269638	221937	47701	82.3	21	12840
16 Mar	1341	28	238186	238186	0	100.0	22	10633
17 Mar	733	30	198171	167741	30430	84.6	17	11657
18 Mar	1549	31	166035	68166	97869	41.1	22	7547
19 Mar	1714	34	267269	230260	37009	86.2	24	1136
20 Mar	1145	36	254552	166552	87999	65.4	24	10606
21 Mar	1802	38	237138	104727	132411	44.2	24	9881
22 Mar	990	27	--	209850	--	100.0	20	--
23 Mar	672	23	--	158923	--	100.0	18	--

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
24 Mar	240	18	--	131874	--	100.0	16	--
25 Mar	1192	19	--	206580	--	100.0	23	--
26 Mar	1555	22	--	137522	--	100.0	23	--
27 Mar	1751	22	--	132667	--	100.0	18	--
28 Mar	1793	33	--	295092	--	100.0	24	--
29 Mar	1449	41	334368	269396	64972	80.6	22	15199
30 Mar	0	35	88379	88379	0	100.0	6	15370
31 Mar	1557	30	209052	149015	60037	71.3	18	11614

SOLAR TEST HOUSE DATA SUMMARY

March 1977

Days of Record Considered - 31

Total Hours Analyzed - 643

House Heating Demand - 6,532,235 Btu
(Hourly) - 11,308 Btu/Hr)

Average Solar Insolation - 1,233 Btu/SF

Average Number of Degree Days - 31.8

Btu Available to Solar Arrays - 22,718,737

Btu Collected by Solar Arrays and Storage Tank - 10,538,960
(46.4% of that available)

Btu Provided to House for Heating by Solar Energy - 4,342,146
(66.0% of heating demand, 50% eff) (19.0% of that available)

Date	Solar Insolation (Btu/SF/Day) Cum,Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
1 Apr	1461	29	83	89	338561	114804	34	360063	136594	38	
2 Apr	481	37	86	85	110279	0	0	117479	0	0	
3 Apr	1460	21	82	85	338352	88000	26	359853	0	0	
4 Apr	1105	34	83	83	252363	62596	25	268973	0	0	
5 Apr	--	25	--	--	--	--	--	--	--	--	
6 Apr	1797	21	84	103	410412	339991	83	437429	392379	90	
7 Apr	1561	17	88	101	345614	198067	57	370041	278831	75	
8 Apr	1674	16	90	102	357956	130775	37	385311	295841	77	
9 Apr	1575	12	92	114	337689	250398	74	363348	262376	72	
10 Apr	1332	4	109	116	287100	147526	51	308660	179822	58	
11 Apr	797	22	110	109	155381	33428	22	169760	40772	24	
12 Apr	1425	26	94	105	302444	129231	43	325912	120097	37	
13 Apr	1004	22	92	98	211183	113117	54	227897	119256	52	
14 Apr	459	20	84	84	82017	6896	8	90969	11091	12	
15 Apr	--	27	--	--	--	--	--	--	--	--	
16 Apr	2177	20	89	100	--	--	--	--	--	--	
17 Apr	2079	17	91	113	393802	295222	75	432321	267219	62	
18 Apr	1208	21	109	110	229326	126581	55	251674	138292	55	
19 Apr	513	27	97	97	95724	2188	2	105375	0	0	
20 Apr	1397	30	78	88	270010	169309	63	295406	184824	63	
21 Apr	2212	24	82	103	406847	277483	68	448945	287685	64	
22 Apr	2211	21	88	109	398611	377409	95	441422	359793	82	

Date	Solar Insolation (Btu/SF/Day) Cum,Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	Btu's Available	Btu's Collected	%	Btu's Available	Btu's Collected	%	
23 Apr	1540	17	97	105	276665	164576	59	306556	199082	65	
24 Apr	2037	18	96	110	365902	316755	87	405469	319308	79	
25 Apr	1925	17	100	116	339069	316182	93	377045	314884	84	
26 Apr	1710	15	104	115	300301	233711	78	334117	232068	69	
27 Apr	1580	5	106	114	168184	190716	113	209276	188198	90	
28 Apr	1159	13	105	107	161890	119484	74	188567	76135	40	
29 Apr	1651	14	102	108	--	--	--	--	--	--	
30 Apr	593	12	102	115	--	--	--	--	--	--	

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
1 Apr	1461	29	203371	193502	9869	95.1	24	8474
2 Apr	481	37	208074	0	208074	0	24	8670
3 Apr	1460	21	227813	0	227813	0	24	9492
4 Apr	1105	34	111028	0	111028	0	16	6940
5 Apr	--	25	--	--	--	--	--	--
6 Apr	1797	21	106313	98088	8225	92.3	15	7088
7 Apr	1561	17	0	0	0	0	17	0
8 Apr	1674	16	--	106312	--	100.0	24	--
9 Apr	1575	12	--	110275	--	100.0	15	--
10 Apr	1332	4	0	0	0	0	17	0
11 Apr	797	22	--	18330	--	100.0	24	--
12 Apr	1425	26	--	176856	-	100.0	23	--
13 Apr	1004	22	77274	58358	18916	75.5	23	3360
14 Apr	495	20	--	145250	--	100.0	10	--
16 Apr	2177	20	30430	0	30430	0	24	1268
17 Apr	2079	17	80522	73120	7402	90.8	24	3355
18 Apr	1208	21	--	97494	--	100.0	23	--
19 Apr	513	27	--	188845	--	100.0	22	--
20 Apr	1397	30	207385	185179	22201	89.3	24	8641
21 Apr	2212	24	124223	42802	81421	34.5	24	5176
22 Apr	2211	21	--	122759	--	100.0	24	--

Date	Solar Insolation (Btu/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (Btu's)				Time Interval Analysis	Average Hourly Heating Demand Btu's/Hour
			Total	Solar	Gas	% Solar		
23 Apr	1540	17	--	93432	--	100.0	17	--
24 Apr	2037	18		55286			22	
25 Apr	1925	17		79362			23	
26 Apr	1710	15		61429			24	
27 Apr	1580	5		51422			19	
28 Apr	1159	13		117112			23	
29 Apr	1651	14		14069			15	
30 Apr	593	12		20906			17	

SOLAR TEST HOUSE DATA SUMMARY

April 1977

Days of Record Considered - 28

Total Hours Analyzed - 607

House Heating Demand - 2,866,000
(Hourly) - (4722 Btu/Hr)

Average Solar Insolation - 1398 Btu/SF

Average Number of Degree Days - 20.1

Btu Available to Solar Arrays - 14,517,542

Btu Collected by Solar Arrays and Storage Tank - 8,608,993
(59% of that available)

Btu Provided to House for Heating by Solar Energy - 2,110,189
(74% heating demand, 50% eff) (14.5% of that available)

APPENDIX C

NATURAL GAS AND ELECTRICITY CONSUMPTION

NATURAL GAS CONSUMPTION (FT^3)

STH

Month	Total	Heating	DHW	Stove
F[1]	7,600	6,510	1010	80
M	17,480	15,210	2180	90
A	13,200	9,360	3320	520
M	10,170	6,310	3310	550
J	5,700	1,680	3380	640
J[2]	4,740	1,310	2520	910
A	3,510	1,360	1670	480
S	9,050	4,880	3530[3]	640
O	11,950	7,870	3680	400
N	18,250	14,720	3110	420
D	29,760	24,430	4000	1330
J 1977[4]	--	--	--	--
F	9,420	7,620	1480	320
M	13,090	8,990	3370	730
A	5,830	2,190	3000	640
Total	159,750	112,440	39,560	7750

[1] Last half of month only

[2] Furnace tests and house guests

[3] New baby (diapers)

[4] Meters removed 3 Jan-10 Feb

NATURAL GAS CONSUMPTION (FT^3)

CH

Month	Total	Heating	DHW	Stove
F[1] 1976	13,540	11,550	1890	100
M	27,720	23,010	4020	690
A	21,250	16,330	4280	640
M	14,450	9,980	3820	650
J[2]	6,800	3,620	2750	430
J[3]	4,270	1,570	1650	1050
A	5,580	2,100	3000	480
S	12,090	7,600	3740	750
O	16,360	12,600	3720	640
N	24,040	19,630	3720	690
D	31,240	27,220	3450	570
J[4] 1977	29,920	25,930	3480	510
F	25,180	20,320	4290	570
M	24,280	19,640	4050	590
A	20,420	14,780	4820	820
Total	277,740	215,880	52,680	9180

[1] Last half of month only

[2] House empty two weeks

[3] House guests 23 Jun-6 Jul

[4] House empty two weeks

ELECTRICITY USAGE

STH
(KWH)

Month	Fan	RA	HC	GA	DHW
M 1976	158.7	97.8	33.5	116.3	--
A	124.1	122.3	29.7	132.8	--
M	53.6	122.0	16.6	127.2	--
J	17.8	99.0	5.3	105.2	4.0
J	0.2	74.1	0.2	75.7	5.8
A	1.0	84.4	0.4	100.5	20.0
S	27.0	100.1	4.6	114.3	9.4
O	97.7	100.2	23.5	107.8	9.9
N	159.0	88.4	34.2	87.3	5.9
D	179.9	97.4	33.8	98.0	5.9
J 1977	239.9	108.3	47.1	104.9	13.9
F	--	--	--	--	--
M*	335.0	206.0	73.0	215.0	10.0
A	69.0	93.0	21.0	96.0	7.0
Total	1,462.9	1,393.0	322.9	1,481.0	91.8

* February and March combined